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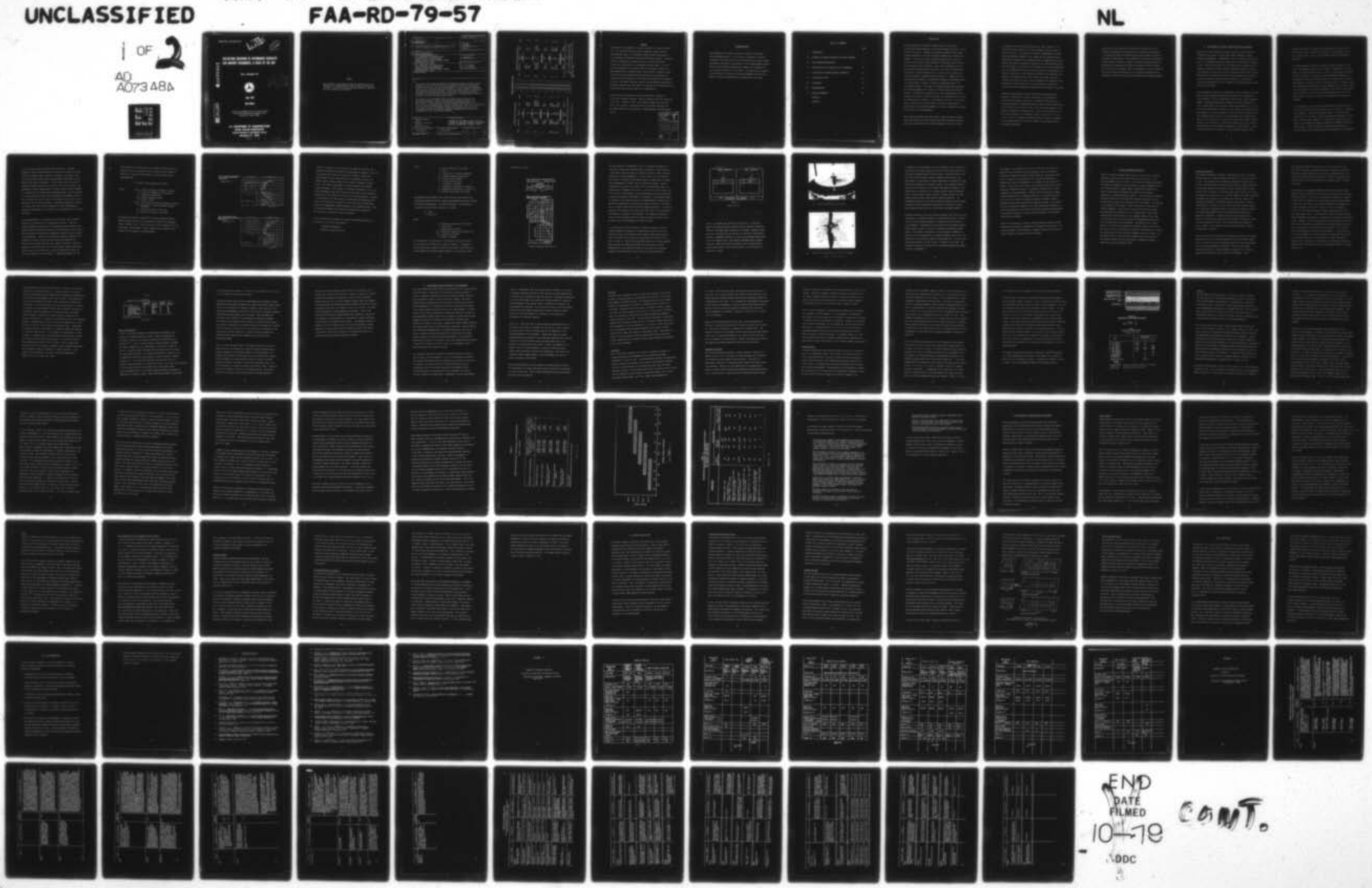

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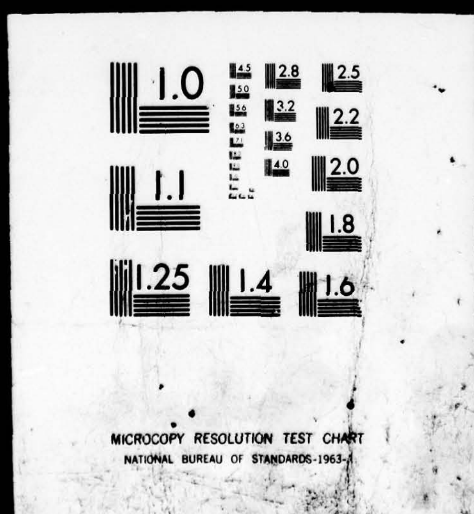

Report No. FAA-RD-79-57

REFLECTION CRACKING OF BITUMINOUS OVERLAYS FOR AIRPORT PAVEMENTS, A STATE OF THE ART

Aston L. McLaughlin, Ph.D.

May 1979

Final Report

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FEDERAL AVIATION ADMINISTRATION
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16. Abstract

This report surveys current methods and practices pursued by various pavement authorities in an effort to reduce the incidence of reflection cracking of bituminous overlays. The most common theoretical, analytical and laboratory efforts in this connection are also presented. Latest information concerning these measures and their successes, failures and uncertainties is stated from interviews with cognizant personnel in the field, and at universities and government research agencies. Other information is presented from construction records, site visits and published material.

The findings in this research effort are that the state of the art in preventing reflection cracking of bituminous overlays, excluding a few institutional efforts, has not developed along systematic lines and, to date, there is no methodology by which the degree of effectiveness of any method in place can be predicted under a variety of conditions. Also, field experimentation has not yielded reproducible results partly because of lack of good experimental design and statistical methods, adequate quality control and documentation of all significant variables.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

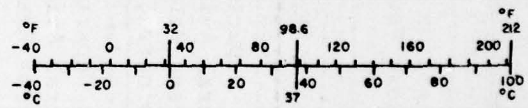
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

pound force (lbf) = 4.448 Newton (N)

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



giga (G) = 10^9

PREFACE

This report is in response to a request, AAP-580-77-2, dated September 26, 1977, from the Office of Airports Standards, Federal Aviation Administration (FAA), to investigate current practices and theories in the control of reflection cracking of bituminous overlays. Reflection cracks are fissures in an asphalt overlay or surface course that reflect the crack pattern of the pavement structure below. The study has been conducted as an in-house effort by the Systems Research and Development Service, Airport Division, and involved a literature search together with site investigations and interviews with engineers and contractors having expertise in the design and construction of bituminous overlays. This report describes research work performed by universities, government agencies and other groups, and outlines the conclusions that were reached from those efforts together with commentaries.

The work plan was coordinated with (and reviewed by) engineers in the Office of Airports Programs. Work was conducted under the supervision of Mr. Carl L. Schulten, Chief of the Airport Pavement and Facilities Branch. Mr. Charles L. Blake was Chief of the Airports Division and Mr. Robert Wedan was Acting Director, Systems Research and Development Service.

ACKNOWLEDGEMENTS

The cooperation of regional and district offices of the Federal Aviation Administration, U. S. Army Corps of Engineers, university researchers, engineers at civil aviation airports and at state highway departments, and finally, of personnel at the Fairbank Highway Research Station, Federal Highway Administration (FHWA), was invaluable for the successful completion of this effort. The Engineering and Specifications Division in the Office of Airport Standards also gave vital support during the investigations and preparation of the report.

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I. INTRODUCTION

The rapid growth in the nation's economy since the early 1940's necessitated the proliferation of airport and highway facilities in every corner of the nation. Highways and airports financed by public works programs responded to the need for greater communication, commerce and mobility. The need for airport pavements became so great that many military airfields built during World War II have been pressed into service at general aviation airports. Many of these pavements were constructed with portland cement concrete but a few were of flexible type construction. Some construction was, of course, only the result of a need for widening or extending existing facilities. However, all construction must necessarily be rehabilitated because of deterioration due to constant usage or because of exposure to weathering action from environmental forces. This need was invariably satisfied by overlaying the existing pavement with a topping of either concrete or bituminous material. Unfortunately, rehabilitation in most instances was only of cosmetic value since the underlying causes of the deterioration were often not removed prior to overlay. A new problem then resulted; the overlays after a short period of service began to reflect the same pattern of deterioration as the original pavement or, at best, cracked with the same joint pattern as the base pavement.

Many different materials have been tried to combat reflection cracking and several reports have been written about field observation projects. While some successes have been noted by engineers on certain projects,

no predictable results have been experienced. Basic research on the mechanisms by which cracks in an existing pavement reflect through an overlay is sparse. The reasons for volumetric displacements are understood from elementary physics. But, forces that are developed during contraction or expansion of a pavement because of temperature or moisture changes, the degree of resistance rendered at the interface between pavement and overlay, the coefficients of expansion of the several components, the rate of temperature variation through the depth of the pavement, the influence of moisture on this temperature variation, the stiffness of the subgrade, the compacted state of the various soil lavers, and other variables with transient values, have not generally been addressed during the planning of field tests and it has been found that successes or failures can never be explained or duplicated with any degree of certainty.

Impressive success rates in reducing reflection cracking have been observed in cases where the overlay would have to be considered as increasing the structural strength of the pavement either because of increased thickness of bituminous material or because large crushed stones of the order of 3-1/2 inches (8.9 cm) or more are placed between the old pavement (regardless of condition) and a 4 inch (10.2 cm) overlay. The most certain occurrence of reflection is seen in cases where a 3 inch, 7.6 cm, (or less) thickness of bituminous overlay is laid on a pavement that has deteriorated due to adverse climatic or load related factors and subgrade subsidence.

Conclusions are that reflection cracking can be reduced only after a theoretically based model considering all the various soil parameters is developed and after this model has been field validated and applied to pavement overlay design. This validation will require the observation of test strips in which each variable is strictly controlled and after a methodology for quantifying the amount of cracking has been developed. The trial and error procedure, which is now prevalent, cannot be expected to deliver useful results because all the operating variables are not identified or quantified and follow-up observations are seldom systematic.

II. THE MECHANICS OF OVERLAY INTERACTION WITH THE PAVEMENT

Pavements are active systems of specially selected, layered materials intended for the support of loads (wheel loads, primarily) without excessive displacements. Displacements, both in translation and rotation, occur in all directions and under normal conditions are within tolerable limits. Strains that exceed limits of recovery for the materials may be induced by a variety of factors and when these occur pavement rutting or cracks develop at points that will most effectively relieve high stresses. Redistribution of stresses then occurs and the pavement will continue to function, usually at a reduced level of efficiency. The principal sources of displacements are load, temperature, moisture migration, creep, swell, and frost heave.

The displacements induced by any combination of these factors have not yet been precisely formulated mathematically because of the complexity of stress patterns in such an inhomogenous, barely elastic, three dimensional medium. Although semi-empirical formulations have been developed and have, to some extent, been verified by field testing devices, it is still not known to what extent an asphaltic overlay affects the movements of the base pavement. The usual assumption is that the overlay follows the movements (induced by all causes) of the base pavement and in addition may move (or fail to move) on its own and out of phase with the base pavement because of such influences as temperature gradients with depth, material characteristics, and the absence or presence of tractive forces. Stress relief by cracking of the overlay is thus a complex function of base

pavement displacements, overlay planar displacements and the presence of pre-existing cracks. By definition, however, only those overlay cracks with the same pattern as that of the pavement below are considered as reflective.

In flexible pavements, loads are supported by shear developed by interlock in the pavement layers and by resistance to compression in the subgrade, with minimal pavement flexure. Failure of the subgrade to provide sufficient resistance to compression without permanent deformation is evidenced by rutting of the surface course which traditionally has never been designed to resist high levels of shearing forces. An asphalt overlay laid over pavements supported by failing subgrades will of necessity crack in the same manner as the existing pavements. This fact has been observed on many occasions in the field and remedial measures have, in the more severe cases, been taken to stabilize the subgrade before overlay was attempted.

In rigid pavements, the load carrying capacity derives from bending by plate action mitigated in varying degrees by the resistance to compression in the subgrade. Insufficient subgrade support of a portland cement concrete slab, for instance, creates large flexural displacements as the slab is forced to span between (or to cantilever over) points of hard support with attendant high bending stresses and ultimately formation of natural hinges. Hinges are points of angular discontinuities and continual flexure here causes progressive deterioration of the pavement.

At joints which had been provided during construction, subgrade subsidence, whether from overstress or the effects of water, may cause faulting of adjacent slabs resulting in roughness, high impact loads from aircraft wheel loads, pumping and progressive dislocation of soil material from under the pavement. In more severe cases, the growth of vegetation occurs as particles of soil rise to fill the fissures. The magnitude of vertical displacements at adjacent edges cannot be impeded by the addition of an overlay which invariably cracks at these locations. An overlay across the hinges does not strengthen the pavement structure, does not remedy the initial cause of the distress, and will fail in the same manner as the original pavement. Successful prevention of cracks in the overlay (this factor alone considered) has been accomplished by jacking and replacement of lost material in the subgrade prior to overlay operations.

Planar displacements of the pavement structure derive from volumetric expansion or contraction due to temperature variations. Daily and seasonal temperature changes result in measurable planar movements that develop enormous stresses when tractions are developable on the boundaries. These tractions arise partly from interlayer friction and partly because of end restraints. High tensile stresses are generally relieved by the formation of natural crack lines whose location and magnitude are determined by the cross sectional area, material properties, interface roughness, cracking strength, rate of crack growth, thermal coefficient, imperfections in the cross section, amount of temperature change, and the planar dimensions of the pavement. A simplified approach for the

determination of jointed concrete slab movements under the action of temperature may be developed from basic equations from strength of materials.[1] Horizontal displacements at joint locations may be approximated by:

$$\Delta_h = (\alpha \Delta T_h L) - (\gamma_c h_c + \gamma_{ac} h_{ac}) f (L^2/2)(1/A_c E_c)$$

where,

h_c, h_{ac} = height of concrete and asphalt concrete,
h = horizontal movement at joint location,
α = temperature coefficient,
ΔT_h = average temperature drops,
L = length of slabs
γ_c, γ_{ac} = unit weight of concrete and asphalt concrete,
f = coefficient of friction between subgrade and slab,
A_c = unit cross section of slab, and
E_c = modulus of elasticity of concrete

The results of analytical simulations of overlay systems by finite element methods were used by investigators to develop the nomographs shown in Figures 1 and 2. From the study, it was concluded that for any given planar joint movement, overlay stresses can be assumed to vary linearly with the amount of induced movement.

Figure 1. Top fiber stress in overlay because of joint movement in a joint-reinforced concrete pavement.

(After Ref. 1)

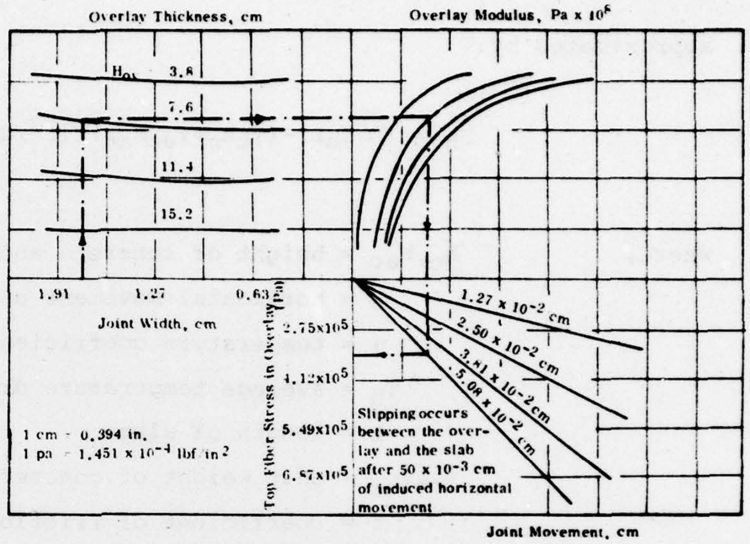
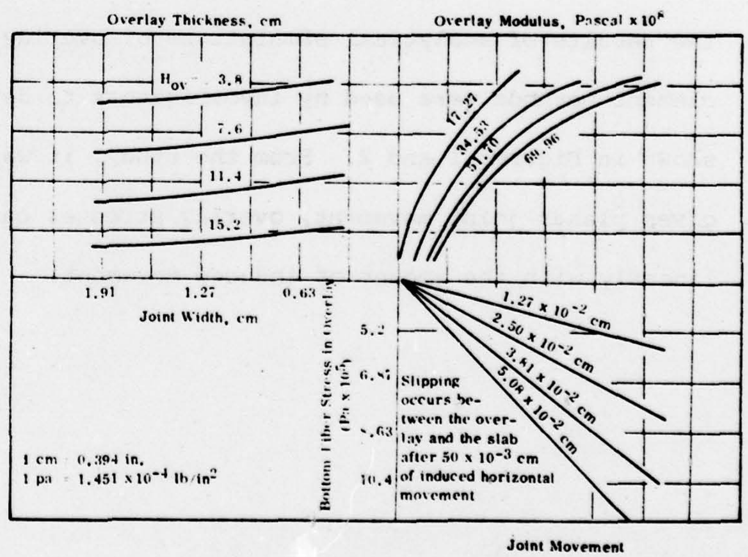


Figure 2. Bottom fiber stress in overlay because of joint movement in a joint-reinforced concrete pavement.

(After Ref. 1)



Changes in curvature of rigid pavements are commonly induced by high temperature differentials between the bottom and top surfaces of the slab. This curling action raises the slab off its support, creates high flexural dead (or live) load stresses in the pavement structure and demands greater bearing strength from the base or subgrade at contact points. The result, predictably, is failing stresses with eventual cracks developing. Little change in the amount of movement occurs in the existing pavement after overlay and none of the other factors originally contributing to the creation of cracks in the existing pavement is reduced by the presence of the new surfacing. Researchers have determined that the use of overlays up to 4 inches (10.2 cm) thick have no significant effect on the temperature induced movement of the underlying slabs. Also, the horizontal movement of the slab was the same after cracking of the overlay as it was before cracking occurred.[2]

It is also possible to estimate the curling and warping deflections by the solution of the basic relationship,[1]

$$[(d^4w/dx^4)+(2d^4w/dx^2dy^2)$$
$$+(d^4w/dy^4)]=\{(q/D)-[K(w-c)/D]\}$$

where,

w = plate deflection in x,y plane,

q = load,

$D = [E_c h_c^3/12(1-\nu^2)]$ = plate stiffness,

E_c = concrete modulus of elasticity,

h_c = concrete slab thickness,

ν = concrete Poisson ratio,

$c = (\alpha \Delta t d^2/2h_c)$ = curling,

α = temperature coefficient of concrete,

Δt = temperature differential in slabs, and

d = distance from center of the slab.

The maximum stress induced in the overlay over the joint locations of concrete base slabs may also be computed approximately from basic strength of materials relationships. The following formula , also reproduced from work at the Ohio State University, is useful;

$$R = (j/2\theta)$$

$$\sigma = (E_{ov}H_{ov}/j)\theta$$

where,

R = radius of curvature of the overlay,

j = joint width,

θ = edge slope of the slab,

E_{ov} = modulus of elasticity of overlay, and

H_{ov} = thickness of overlay

σ = stress in overlay

An illustration of the rotation of the overlay at the joint location due to curling of the base slab is shown in Figure 3. A nomograph relating edge slope, pavement thickness, slab length, joint width, and overlay modulus with induced bending stresses in the overlay is also

reproduced in Figure 4.

Figure 3. Bending of overlay by vertical movement of joint.

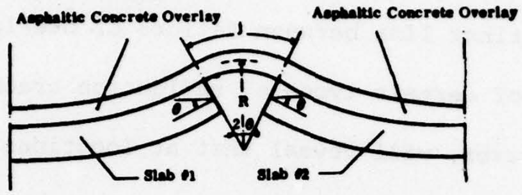
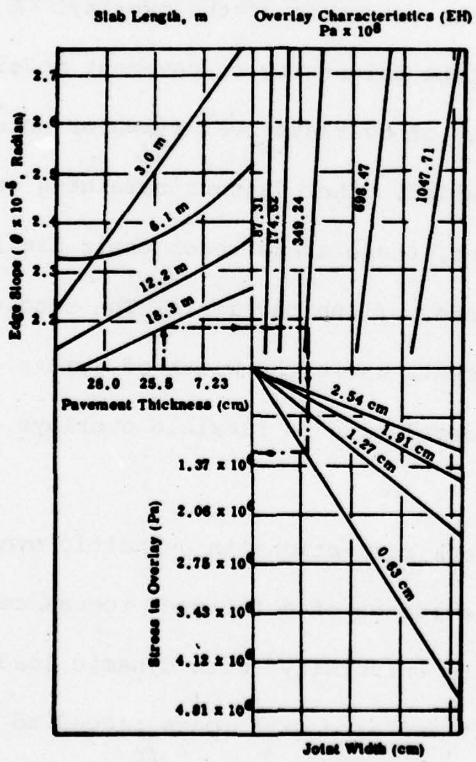


Figure 4. Maximum stress in overlay because of %°C temperature differential in a rigid pavement.



Note: 1 cm = 0.394 in, 1 m = 3.3 ft, 1 Pa = 0.000 145 lbf/in^2.

(Figures reproduced from Ref. 1)

The most sustained and methodical effort at studying the mechanics of reflection cracking and developing analytical models is being conducted at Ohio State University where one approach has been to treat reflection cracking as a fatigue phenomenon. At first glance, it is not apparent that there is a distinct link between failure of overlays due to fatigue and the phenomenon of certain types of reflection cracking. Further considerations, however, will reveal that at locations where there is a discontinuity in pavement cross section, a flaw in the cross section, and cyclic stress or displacement, high stresses develop and cause propagation of cracks up through the thickness of the overlay. A considerable amount of research at Ohio State University on pavement models has shown that the fatigue life expectancy of overlays over flaws or notches in a base pavement is severely curtailed, other factors remaining constant. As loads are applied to the pavement, these areas reach their limit of load repetition long before the remainder of the pavement. The condition worsens over jointed concrete pavements where the width of joints and cracks tend to be larger than those developing in flexible overlays.

To illustrate that crack reflections in asphaltic overlays on jointed concrete pavements is evidence of a fatigue process, certain tests were conducted at Ohio State University[2] with dynamic loads placed directly over the covered joint and also with loads placed to the side of it as shown in Figure 5. Some of the conclusions were that no cracks developed directly under the loaded area because the overlay here was under compression but that cracks would begin at the sides of the load and propagate in both directions along the line of the existing joint.

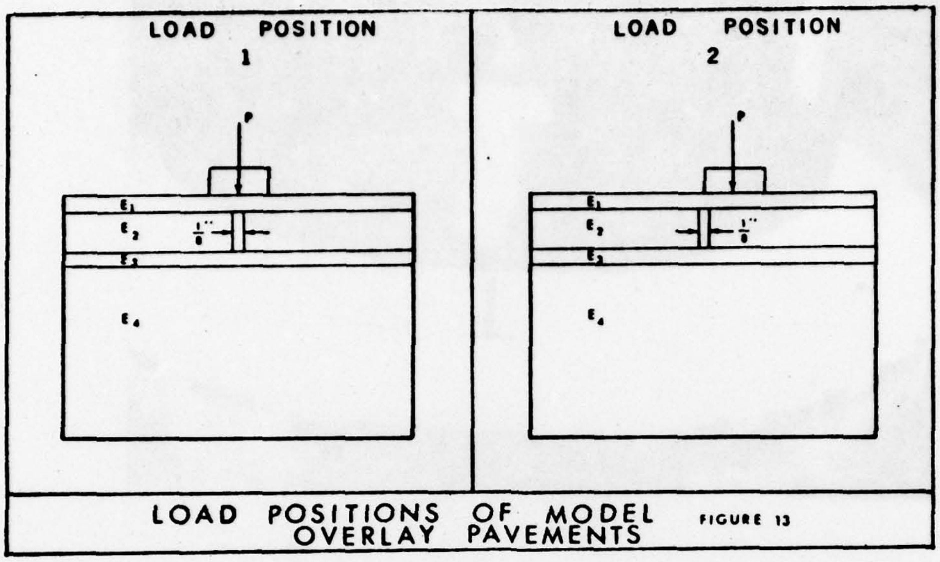
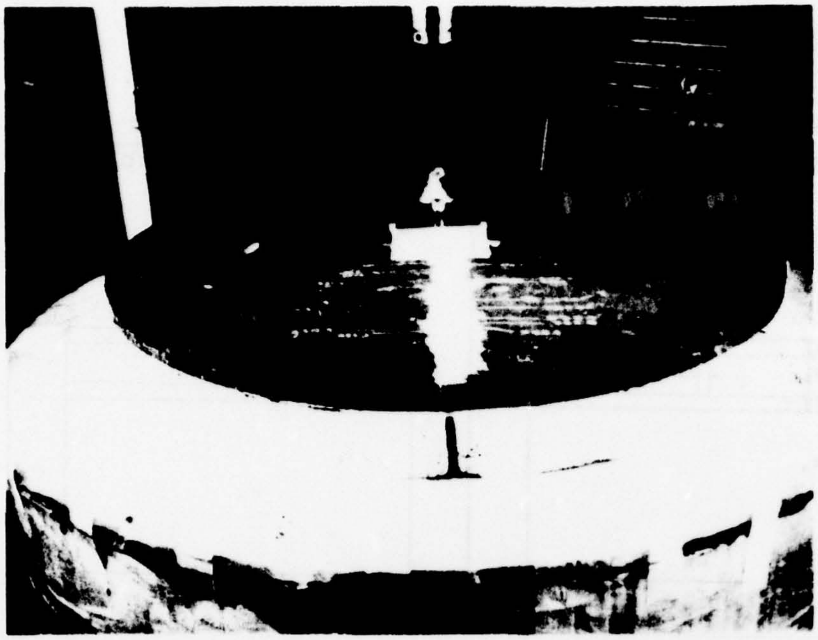


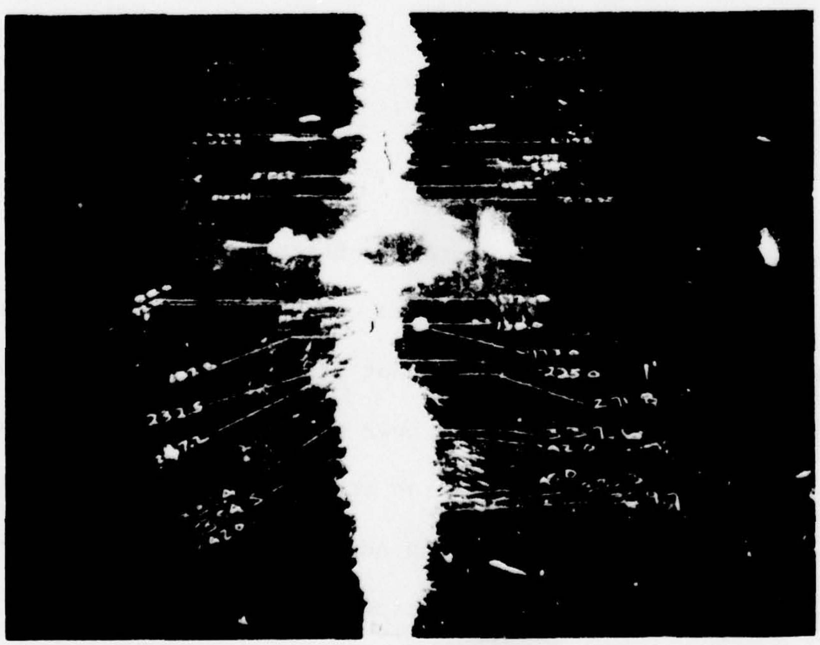
Figure 5

(After Ref. 2)

Figure 6 illustrates the reflection crack pattern. It was also demonstrated that high shear stresses produce an earlier occurence of reflection than when these stresses are not present. Besides, cracks may occur on the bottom of the overlay over the joint if the ratio of concrete to foundation modulus is so high that the neutral axis shifts up into the asphalt layer. The research addressed traffic induced reflection cracking and laid the foundation for a rational design method (which should include thermal effects) for the prevention of reflection cracking.



(a) Model Overlayed Pavement Structure



(b) Reflection Cracking Pattern for Symmetric Loading

Figure 6 (After Ref. 2)

A discussion of the principles of fracture mechanics is not required for this report but the main assumptions are that crack spread occurs in the direction of maximum potential energy density. During one stress cycle the crack tip will undergo alternate sharpening and blunting; and, when there is a large amount of plastic deformation the crack may become blunted and propagation is reduced or halted. The governing equation is that the rate of change of crack length with respect to number of load repetitions is proportional to a constant, based on material property, times a stress intensity factor raised to the power of four (for sand asphalt mixtures tested under monotonic loading conditions). An engineering approach to the fracture problem is based on strain analysis procedures in which mathematical formulations are derived to relate strain energy release rate with crack length and specimen geometry.[3]

Research performed by the Austin Research Engineers Inc.[4] has led to the development of a computer program for incorporating reflection cracking criteria into the design procedure for flexible and rigid overlays on rigid pavements. Sponsorship of the project was by the Federal Highway Administration as part of a policy to upgrade the Interstate Highway system. The program is referred to in the literature as REFLCR1 and requires minor hand computations to determine computer input data. This program will be validated by Resource International Inc., of Ohio, where sensitivity analyses, and modification, if needed, will be made. The states of Florida and Utah have either successfully applied the program or expect to implement it.

A refinement in the formulation that will be necessary for the precise modeling of the reflection cracking phenomenon is that the governing differential equation (at present linear) should be, more properly, non-linear. Another is that the material for the sake of simplicity is assumed to be elastic and homogenous; but, asphalt concrete courses are elastic in only a very small range of their behavior regime and are more accurately considered as plastic, viscoelastic materials that are time, temperature, and load dependent. Besides, while the theory may produce reliable predictions for a homogenous material, it should be noted that this might not be true for a mechanical mixture of bitumen, granular material and voids that characterizes bituminous overlays. Field validations of the analytical models have not been completed and therefore it cannot be determined to what extent more refined assumptions would improve their pedictive capacity, or whether further complexity of the problem would even be worthwhile.

Effective field efforts to reduce or prevent reflection cracking should necessarily be preceded by knowledge of the reasons for the cracks in the existing pavement; random changing of pavement variables has not been an effective means of reducing reflection cracking.

III. EXISTING PAVEMENT MODIFICATION

Some of the earliest methods which proved to be effective in retarding reflection cracking involved obliterating the crack pattern in the existing pavement prior to overlay. One of these, "breaking and seating," was merely the breaking of the old pavement into small fragments by the use of heavy rollers or impact hammers and effectively removing the cavities from between the pavement and subgrade or from between imperfectly interlocked aggregate particles. This method has, reportedly, reduced the span over which temperature movements take place and also assured that all parts of the pavement rest on firm support. An extension of this method is the process of heater scarification of deteriorated flexible pavements. This process has proved to be of great economic advantage when older pavements are to be rehabilitated. While these methods require the destruction of the pavement system, all the cases on record have shown that the materials so produced have been recycled into the production of the new pavement. The effect of all of these methods is to reduce the likelihood of reflection cracks (or the width when they do occur) by assuring full seating on the subgrade and to reduce the expanse over which the underlying fragments contract or expand. The resulting tensile or shearing strains imposed on the cross section of the overlay, whether they are load related or temperature related, should then be within tolerable limits.

Breaking and Seating

The Minnesota Department of Highways investigated the effect of breaking and seating portland cement concrete pavements prior to overlay as early as 1959. The selected area of roadway for rehabilitation was 18 miles (29 km) long and had been constructed 18 years before. Some of the observations made centered on the amount of cracks reflecting after various periods (up to 30 months) at transverse joints, and at center line joints. An average of 10 passes of a 59 ton (525 kN) rubber tired roller effectively overloaded those sections of the pavement that were not seated on the subgrade and produced a considerable number of new cracks. Condition surveys after 2 1/2 years of rural traffic usage since overlay revealed that rolling had a measurable effect on decreasing the number of reflection cracks when compared to those sections that were unrolled for purposes of comparison. Overlay thickness was also varied and the amount of reflection also decreased with thickness of overlay, all other conditions remaining the same.[5] Results were definitive enough to cause a change in the department's policy which then began to require rolling prior to overlay.

During this period, the practicality of breaking and seating old concrete pavements with a 50-ton (445 kN) pneumatic roller and an impact hammer prior to overlay with hot mix bituminous material was also investigated by the Louisiana Department of Highways.[6] The section of roadway selected consisted of a concrete pavement 6 inches (15.2 cm) thick, in generally poor condition, with a great deal of pumping. It was

also concluded, based on observations after a few years of service, that use of the roller and hammer drastically reduced the occurrence of reflection cracking essentially because of the improved seating of the slab on the subgrade (ML and CL type soil in the Unified Classification System) at the joints and the presence of a leveling course just under the overlay.

The Washington State Highway Commission was also interested in experimentation into the effects of heavy rollers in seating concrete pavements during this period.[7] One plan for rehabilitation required the towing of a 50-ton (445 kN) compactor over an old, poorly seated concrete pavement 6 inches (15.2 cm) thick. This was then followed by the placement of a layer of untreated crushed rock 5 inches (12.7 cm) in thickness. A 3-inch (7.6 cm) minimum thickness of asphalt concrete was then laid as the final surface course. A survey after 18 months of service revealed that the measures were effective in retarding the occurrence of reflective cracks. However, it was not determined how much contribution was derived from the act of breaking the pavement prior to overlay and how much was due to the presence of the crushed stone interlayer. This method has also received attention in New York and New Mexico. A clear conclusion of the effectiveness of the method studied in the New York[8] tests could not be drawn because the new overlay was much thicker than what was normally used. Some delay in the appearance of reflection cracking was noted but this could have been due to the increased thickness of overlay that was used.

Much research has in recent years been done in Canada on the causes and prevention of reflection cracking. A study performed in the Ontario Ministry of Transportation and Communication[9] revealed that pulverization of an existing rigid pavement surface and the reuse of this material as a base for resurfacing is the most viable alternative to conventional resurfacing. The testing procedure for this study consisted of treating the pavement by seven different methods which included an interlayer of screenings, granular interlayer of two different sizes, open graded binder interlayer, replacing the surface entirely, pulverizing the surface and reusing it, or adding an enriched asphalt mix to the pulverized pavement. The performance of these surfaces were compared over a 5-year period with that of a conventionally constructed overlay. Comparisons were made in terms of the percentage of reflection cracks that appeared in the control test section. In the summary of findings which is shown in Table 1, it appears that surface pulverization and reuse was the most cost effective of the treatments considered. It should be noted that the conclusions were based on 1971 bid prices for five construction methods, the life of the initial investment, and the estimated maintenance costs necessary to keep the pavement in a usable condition. In the comparison of performances, the control (untreated) pavement was assumed to have a life span of 10 years.

Table 1

Summary inferences from Trout Creek test road.

Section	Treatment	1976 Cracking (percentage of control)	Construction Difficulties	Extra Cost* (percentage of control)	Further Consideration
1	Screenings interlayer	72	Considerable	27	No
2	7.6-cm granular interlayer	36	Moderate	32	Yes
3	15.2-cm granular interlayer	26	None	67	Yes
4	Open-graded binder interlayer	81	None	0	No
5	Surface replaced	10	None	23	Yes
6	Surface pulverized	4	Moderate	31	Yes
7	Surface pulverized and enriched	3	Moderate	86	Yes
8	Conventional resurfacing	100	None	0	Control

Note 1 cm = 0.39 in

*Based on 1971 bid prices for the test road sections.

(After Ref. 9)

Heater Scarification

In 1970, the Arizona Department of Transportation formulated a test program on 18 highway sections in order to study the mechanisms of reflection cracking and to develop new methods and materials for its prevention.[10] A total of twenty different existing pavement treatments and overlay compositions were investigated. After nearly 4 years of service, a condition survev was made and this included the use of photography and computer methods. For certain combinations of conditions such as temperature variations, water migration, traffic intensity, subgrade strength, etc., it was concluded that heat scarification of the old asphaltic concrete pavement to a depth of 0.75 inch (1,9 cm) and its rejuvenation to 200/300 penetration prior to overlay with a slow aging, lowest viscosity asphalt (AC 2.5) was the most effective means of retarding the appearance of reflection cracks. These findings were based on percentages

of cracks reflecting through a 1.25-inch (3.2 cm) overlay with a 0.5-inch (1.3 cm) asphalt concrete friction course.

Additional results from the test program showed that an asphaltic rubber membrane or rubber seal coat between the overlay and friction course ranked highly in the prevention of reflection cracking. Also, one of the five best methods recommended by the report was the use of a fiberglass membrane between the existing pavement and the overlay. This performed more efficiently than Petromat, but presented more installation problems. The results of the comparison were clouded by the fact that more asphalt was used when fiberglass was installed than when the Petromat was installed. It should also be noted that all test sections were not compacted to the same density and that rideability, rutting, and aging considerations should have been evaluated when comparisons of the various test sections were made.

Some of the most intensive usage of the heater scarification process in combination with the addition of a plasticizing agent has been made on airport pavements in the southwest region of the United States. The upgrading and overlay of old military and civilian airfields for general aviation purposes have been effected at Santa Fe, Grants, Las Vegas, Farmington, Roswell, and Hobbs, in the state of New Mexico and at air carrier airports at Carlsbad, New Mexico, and El Paso, Texas. Scarification was to a depth of 3/4 inch (1.9 cm) before overlay. The primary reasons for the choice of this process prior to overlay had been to

create a positive and effective bond between the old pavement and the overlay, and to smooth out rough spots. However, a beneficial byproduct has been the retardation of reflection cracks in the new overlays. Reports state that at an old army airbase at Pampa, Texas, one pavement constructed during the Second World War was densely cracked with fissures ranging from 1/4 inch to 2.0 inches (0.6 cm to 5.1 cm) wide. This pavement was subjected to severe temperature variations. After it was scarified and overlaid it became apparent that reflection cracking had not occurred to the same extent as it occurred at a Deming, New Mexico, airport where it was decided not to scarify. The pavement at Pampa is reported to be now 10 years old with very little reflection cracking. Experiences in this area also tend to endorse the belief that heater scarification along with the addition of an emulsifying agent is an effective means of inhibiting reflection cracking.

IV. MODIFICATION OF THE CHARACTER OF THE INTERLAYER

While some emphasis has been placed on the preparation of the base pavement prior to overlay, a great deal of attention has now been directed at trying to change the characteristics of the interface between base pavement and overlay in order to reduce reflection cracking. One reason derives from the recognition that factors which influence the amount of strain developable in the overlay cross section include the gage length of the overlay spanning cracks or joints in the base pavement. A second reason for this focus of attention is the belief, based on the nature of crack propagation through solids, that the growth of cracks from the base pavement up through the overlay can be arrested if suitably chosen materials are placed in their path. Highway and airport pavement engineers have applied thin layers of agricultural lime, stone dust, sand and fabrics over cracked base pavements prior to overlay operations. This was an effort to reduce the bond stress between the overlay and the pavement thereby increasing the span for planar displacement, and consequently decreasing the strain in the overlay. Others have applied granular material, as large as 4.0 inches (10.2 cm) in size, as an intermediate layer in order to provide crack arrest and relief.

The literature abounds with accounts of field tests and the success or lack of succes, of these methods. But, it is not possible to determine from these accounts what factors contributed to the success or failure of the methods. The need for brevity in these publications, lack of consideration of all the factors peculiar to the pavement systems, varying construction techniques, bias of the observers, and lack of scientific sampling techniques make it impossible to achieve reproducible

results. Consequently, many of the bond breaker techniques are reported as reducing reflection cracking at some sites and the same approach used at another site is reported as being unsuccessful. Sometimes the observers are not the same people, and lacking any standard method for evaluating the performance of the pavement overlay, contradictory accounts of the same pavement are reported. The gross nature of most of the field experimentation has also tended to mask subtle factors that might be deterministic of the effectiveness of the methods in the prevention or retardation of reflection cracking.

There is no doubt that some of these methods have beneficial effect on the overlay with regard to cracking, but very little, if any, attention has been placed on corollary effects that are not beneficial to the overall performance of the pavement. Taxiway exit ramps and runway touchdown areas are locations of high horizontal shearing forces and over-reduction of the bond between overlay and base pavement due to the presence of a bond-breaker could result in lateral dislodgement of the overlay. Many of the bond breakers are impervious membranes which, under certain conditions of moisture and temperature, could lead to the freezing of water trapped between overlay and membrane and result in loss of integrity of the overlay.

The following pages will give an account of the work done by a variety of investigators to prevent reflection cracks by providing a bond breaker and crack relief layer. Many of these investigations are still underway and results are only partial.

Lime Dust

A practice that is sometimes used in reducing the incidence of reflective cracking is the application of agricultural lime along joint lines of the base pavement just before overlay. This method has been tried by highway agencies in some western states and at a taxiway overlay at Tinker Air Force Base. According to one oral report, a thickness of about an eighth of an inch of lime was placed on each side of the joint lines in the pavement to be overlaid at Tinker and the customary thickness of asphaltic concrete overlay was then laid. The lime dust was believed to form a bond breaker which increased the gage length of the overlay thereby reducing the strains imposed on it by the contraction or expansion of the joint below. It is also reported that microcracks appeared in the overlay at these locations after some time instead of single large cracks. The effects of lime on the rate of aging of asphalt concrete had not been studied and in most cases where this procedure has been applied follow-up observations have not been systematic.

Stone Dust

One of the earliest studies in the control of reflection cracking of bituminous overlays was performed by the Los Angeles County Road Department[12] as early as 1958. Investigations were based on two approaches, namely, relieving the stresses in the overlay by incorporating expanded wire mesh into the overlay, and increasing the gage length for planar movements by placing a bond breaker between the old pavement and the overlay. The bond breakers utilized included 26 gauge sheet metal, 15-lb (6.8 kg) saturated building paper, 0.001-inch (.03mm) thick aluminum foil,

0.004-inch (.10mm) thick wax paper, and stone dust finer than the no. 4 sieve size. All of these materials were placed in strips over the joints between existing concrete pavement slabs that were previously treated with an application of tack coat. It is reported that considerable construction difficulties were encountered in laying the mesh and the sheet materials. However, the tests were more successfully performed using stone dust that was deposited in the amount of between 1/8 and 1/4 inch (.3 cm and .6 cm) in thickness.

Based on the limited conditions of the tests, this bond breaker was effective in retarding the occurrence of reflective cracks up to a period of 4 years after construction in comparison to untreated areas. The problem of shoving of the unbonded overlay around curves and under braking traffic was not encountered because of the location of the test areas. Also, no problem of freezing moisture, trapped in the granular interlayer, was experienced because temperatures seldom fell below freezing.

Aggregate Interlayer

One of the many methods developed to reduce reflection cracking is to deposit 3/4-inch (1.9 cm) uniform size coarse aggregate on the pavement just before the hot-mix asphalt concrete overlay. Craig Field in Jacksonville, Florida, is a general aviation airport with 100,000 operations annually. When one of its pavements had to be rehabilitated because of severe cracks resulting from weathering and load applications over a 30-year period, it was decided that construction should include

measures to reduce the likelihood of the cracks reflecting through the new overlay. The plans, therefore, required the removal of vegetation from the cracks, removing sand from the cracks, filling these cracks with an asphalt slurry seal, and then applying a uniform size coarse aggregate before topping off with 3-1/2 inches (8.9 cm) of asphalt concrete.

After 4 years of operation, the performance was reported to be excellent and a minimum of cracks reappeared. The performance is attributed to the presence of the interlayer and its influence in preventing the transfer of stresses from the old pavement to the overlay. However, other airports such as those in Wilmington, NC, and in Macon, GA, have had keystone mats with particles ranging from 3/8 to 1/2 inch (1.0 to 1.3 cm) placed on the pavement before overlay and it has been reported that this had no effect in reducing reflection cracking. It should be noted, also, that this interlayer constitutes a permeable course which is undesirable and disallowed for certain applications in civil airport pavement construction.[13]

Arkansas Method

A procedure requiring an open graded interlayer is one that is popular in some of the southeastern states. Historically, when much road work had to be accomplished without the benefit of heavy earth moving machinery, large stones were placed on the roadbed and then secured in place with a steam roller. Hot asphalt was then poured from buckets into the large voids between the aggregate. The application of this procedure to prepare the road surface for an overlay was first introduced in Tennessee in 1950 and after about 20 years was adopted by the State of Arkansas. An

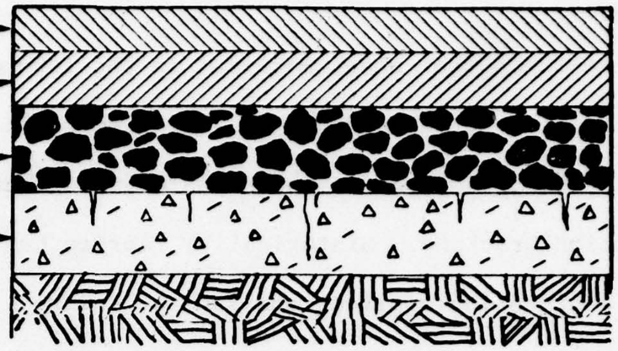
extension of this procedure, commonly referred to as the Arkansas method, requires for the rehabilitation of pavements, an interlayer consisting of large size aggregate (up to 4.0 inches, 10.2 cm, across) which is later covered by a dense-graded leveling course. This course is then topped off with a standard bituminous surface course of sometimes minimal thickness. In some projects, it has been reported that aggregates as large as 6.0 inches (15.2 cm) have been used and the bituminous surface thickness applied above this has reached as much as 4.0 inches (10.2 cm). Total pavement thicknesses of as much as 10.0 inches (25.4 cm) are not uncommon and it has been claimed that none of the original cracks has reflected. Highway engineers familiar with the method attribute the effectiveness to the ability of the large stones to act as a dissipating barrier to the transmission of cracks from the old underlying pavement up through the overlay.[14]

One of the difficulties encountered in this procedure is the provision of the means to drain the crack relief layer which contains from 25 to 35 percent of inplace air voids. To relieve potentially high hydrostatic pressures, this layer is generally carried out into the shoulder area of the pavement, or underground drains are provided near the edge of the pavement to conduct water away from the open graded layer. It has been recommended[15] that compaction of this course be effected only with static rollers (4 to 10 tons, 36 to 89 kN, in weight) and that one complete coverage is sufficient. Overcompaction of the layer may, it is stated, reduce the required high air void ratio which is the vehicle by which cracks in the lower pavement structure are isolated. There is no record

of the application of this method to civil aviation airport pavements.

The worst cases of reflection cracking are associated with the addition of thin overlays (about 2.0 inches, 5.1 cm, or less thick) to badly cracked existing asphalt concrete or portland cement concrete pavements. This type of cracking has less often been a problem on thicker overlays. In areas where 4-inch (10.2 cm) thick overlays have had to be feathered out to 2.0 inches (5.1 cm) or less, reflection cracks appear only in those areas covered by the thinner overlays and disappear where the overlay became thicker. Also, many highway and general aviation airport newly constructed pavements are not thicker than these Arkansas overlays and have given excellent service when the subgrades are of acceptable quality. It would appear that the Arkansas overlay, by virtue of its very thickness and the fact that it is installed over a pavement that had been in operation for some time, would not be susceptible to reflection cracking even without consideration of dissipation of stresses due to the presence of the large aggregate masses.

The Asphalt Institute has published a construction leaflet[15] describing one of these methods which, according to the leaflet, is an effective means for combating reflection cracking. A typical cross section is shown in Figure 7 and the recommended gradation is reproduced in Table 2.



Cross-section
CRACK-RELIEF LAYER OVERLAY SYSTEM

Figure 7
(After Ref. 15)

TABLE 2
GRADATION REQUIREMENTS
(After Ref. 15)

Sieve	Percent Passing A	Percent Passing B	Percent Passing C
3 in. (76 mm)	100	–	–
2-1/2 in. (64 mm)	95-100	100	–
2 in. (50 mm)	–	–	100
1-1/2 in. (38.1 mm)	30-70	35-70	75-90
3/4 in. (19 mm)	3-20	5-20	50-70
3/8 in. (9.52 mm)	0-5	–	–
No. 4 (4.75 mm)	–	–	8-20
No. 8 (2.36 mm)	–	0-5	–
No. 100 (150 μm)	–	–	0-5
No. 200 (75 μm)	–	0-3	–
Asphalt Cement Content (AC-40) (AR-8000)		1.5 - 3.0%	
Aggregate Required:	Sound angular crushed stone, crushed gravel, or crushed slag		
Surface Texture:	Very open and porous (requires covering)		

Fabrics

The likelihood that sheet material in the form of woven or non-woven material will act as a crack relieving material has led to an enormous field testing campaign to investigate its effectiveness in reducing reflection cracking. Historically, fabrics had been very successful in other engineering applications such as subgrade restraint, earth reinforcement, erosion control and water proofing; but, their application as a strengthening material to increase the tensile strength of pavements and to reduce reflection cracking is only a very recent enterprise.

For all applications, more than 6.0 million square yards of fabric were used in 1976 and about 15 million in 1977. Today, there are at least seven major United States corporations manufacturing fabrics from such materials as polypropylene, polyvinylidene chloride, nylon or polyester. A Table prepared by the United States Forest Service, and included in Appendix A, shows some of the physical properties of 20 styles offered by 11 suppliers.[16] Because of this wide usage, the Federal Highway Administration[36] and some manufacturers have developed specifications for the guidance of state and local highway and public works agencies. At present, these specifications do not include criteria directed at reducing reflection cracking although some unproved manufacturers' standards exist to effect this end.

The possible effectiveness of fabrics such as Petromat to prevent reflection cracking has led to their installation in overlay projects on an experimental basis at many civil aviation airports, military airfields, and on roadway

systems in several states from Maine to Texas and from New York to California. As in previously cited methods, the results have been contradictory and their reproducibility can never be achieved. It would appear, however, that when applied over small cracks on asphaltic base pavements more success has been experienced with some of these materials than when they are placed over jointed concrete base pavements. Many agencies such as the Georgia Department of Highways have had better success with fabrics manufactured as adhesive strips which are placed over pavement joints than with sheets that are spread over the whole pavement.

Petromat is a non-woven polypropylene fabric manufactured by the Philips Petroleum Company. According to the literature, this sheet fabric appears to be the most widely field tested material on airport and highway overlay projects. An interview with cognizant personnel revealed that some was laid in a test section at Tampa International Airport in 1977. The area chosen for the test was over a concrete taxiway that had several load related cracks and which had to be overlaid with 2.0 inches (5.1 cm) of asphalt. In order to establish cross slope, this thickness was tapered down to 1.0 inch (2.5 cm) towards the edge of the pavement. An inspection of the control area has revealed the presence of reflection cracks corresponding to joints in the rigid pavement below. But these cracks are more severe in the thinner portion of the overlay and seem to be much narrower in the thicker portion. Where Petromat was laid, the cracks which were progressing from the edge of the pavement stopped at the point where the Petromat began. While it is clear that some factor was

operating to cause the disappearance of the cracks where the Petromat began, it cannot be clearly identified because the overlay thickness was not constant and the edge of the fabric corresponded with the location of much of aircraft wheel traffic.

In this same year, another test section with Petromat was installed at an airport in Wilmington, N.C. The base pavement was of flexible design and was built by the Navy in 1952. Severe distress was evident from the large number of cracks over the surface and it was decided that overlaying with 5.0 inches (12.7 cm) of asphalt concrete could rehabilitate it. Three sections of pavement, each 20,000 sequare feet (1,860 sequare meters), were provided to observe the performance of Petromat, keystone mat, and a control section. The pavement has been in service since 1977 and reflection cracks have not appeared in any of the three types of test locations. It is considered that while this period of service is not sufficiently long for any definitive conclusion to be reached, it is safe to conclude that factors such as extra mat thickness, grade of asphalt, which were common to all sections, were of such a magnitude as to accommodate, without cracking, the amount of movement that the pavement would ordinarily experience. It should also be noted that at this airport, and at about the same time, Petromat was applied over a parallel jointed concrete pavement before 5.0 inches (12.7 cm) of asphalt concrete was laid. It was observed soon after construction that the overlay reflected cracks over the expansion joints. At an area of pavement where

7.0 inches (17.8 cm) of overlay was installed, no cracks have been observed (even over the expansion joints in the base pavement). It would appear that a greater thickness of overlay on jointed concrete pavement is required to prevent reflection than on flexible pavements, all other conditions remaining the same. Personnel from the Waterways Experiment Station have inspected the pavements at these projects and have concluded that Petromat appears to be more effective on asphalt over asphalt than on asphalt over jointed concrete in retarding reflection cracking.[17]

Most of the field observations on the use of Petromat has been conducted by state highway agencies under programs administered by the Federal Highway Administration. One of the earliest efforts was performed by the Colorado Division of Highways.[18] Studies here between 1971 and 1976 indicated that there was some evidence that sheet type material may have some effectiveness in reducing reflection cracking under certain circumstances. Yet, the results were not based on an experimental design so that other factors could be similar in the test sections as in the control section. For example, there was considerable use of leveling courses which effectively increased the thickness of material over the existing cracks. There was also some flushing in the wheel paths of pavements under observation and this would effectively conceal any cracks that would otherwise develop. Also, the fabric was not laid in the passing lane because of fewer cracks there; yet, it is reported that some reflection cracks developed here and were arrested at the edge of the driving lane which had been laid with the fabric.

Other field testing sites where the effects of fabric as a stress relieving device to reduce reflection cracking have been studied include Florida, Iowa, California, South Dakota, Arizona, and Texas. During one project in Texas, two to three miles (3.2 to 4.8 km) of fabric over a width of 50 feet (15.2 m) were laid in one day. The total cost of the project including the installation of 3.0 inches (7.6 cm) of bituminous overlay was $1.13 million. Petromat installation here necessitated an expenditure of $250,000. These expenditures were planned in the hopes of extending the life of the pavement by up to 100 percent (from 5 years to 10 years).

A summary of state highway experience with Petromat is included in Appendix B. It has become evident from reports on the various tests that no definite conclusions can be drawn from the collective results of all the tests. In some instances it would appear that this fabric, and others like it, such as Mirafi, is effective. But, in an apparently similar situation at another location, results contradict previous conclusions. In a memorandum issued in 1978 by the Federal Highway Administration, it was concluded that because of contradictory results and insufficient quantitative data, criteria for the use of fabrics to reduce reflection cracking cannot be developed and their use on pavements must remain on an experimental basis.

However, on the basis of interviews with cognizant personnel engaged in research in the Georgia Department of Transportation, it is evident that "strip type" adhesive fabrics, such as Bidim and others like it, have been effective. It is reported that placing strips over the joints in existing

concrete pavements prior to overlay has not only kept water out of these joints but cracks that might reflect through the overlay are finer (but more numerous) than those in the base pavement. But, other reports from different sources indicate that when narrow strip type fabrics are installed over pavement joints, instead of one crack reflecting, two appear after a very short period of time.

Although results of field tests have not been sufficiently reliable for the development of standards on the use of fabrics to reduce reflection cracking, many manufacturers have developed recommended procedures for their installation. These procedures were developed partly from previous performance and partly from laboratory research that they sponsored. One of these procedures involves the quantity of asphalt that should be used as tack coat prior to the laying of the fabric. Table 3 which is reproduced from an interim report published by the Texas Transportation Institute[19] suggests variations in the amount of asphalt required on a pavement based upon its surface condition. It has been reported that the thickness of tack coat is a critical factor in the ease of installation of fabrics at many sites and it has also been suggested that effectiveness of the fabric as a stress relieving device also depends on this factor.

The grade of asphalt used as a tack coat is also considered to be an important factor which determines effectiveness. It has been recommended that the grade should be one which, in combination with factors such as

pavement and mixing temperatures, will have sufficient viscosity to keep the membrane in place but still be able to penetrate the fabric. Too soft a grade will bleed through the fabric and too hard a grade tends to inhibit the fabric from acting as a stress relieving material. Figure 8, reproduced from an American State Highway and Transportation Officials publication, has been recommended as applicable.

Some research sponsored by Monsanto Textiles Corporation,[20] manufacturers of Bidim, has led to recommendations relating fabric properties with their applications. It is not clear what percentage of cracks can be successfully retarded from reflection when these properties are maintained. Some of the recommendations are reproduced and shown in Table 4. A great deal of laboratory and theoretical research has been conducted at the Ohio State University on the use of fabric reinforcement to optimize the performance of asphalt concrete overlays.[21,22] The essential objectives of the research program were to develop and verify a mechanistic model using fracture mechanics to predict the life expectancy of flexible pavement structures and to investigate the effect of Petromat on the performance of overlays on jointed concrete base pavements. These studies were sponsored by the Federal Highway Administration and, with respect to Petromat, by the Philips Petroleum Company. Some of the important results were that this fabric acts effectively as a crack arrest material and increases the fatigue life of laboratory specimens by up to 12 times at operational stress levels. While the effectiveness in fatigue

TABLE 3

Asphalt Application Rate Correction Due to Existing Pavement

Surface Condition

Description of Existing Surface	Approximate Surface Texture, cubic inch per square inch (cm^3/cm^2)*	Asphalt Quantity Correction, gallon per square yard (ℓ/m^2)**
Flushed Asphalt Surface	0.001 to 0.005 (0.002 to 0.013)	-0.06 (-0.27)
Smooth, Nonporous Surface	0.005 to 0.015 (0.013 to 0.038)	-0.03 (-0.14)
Slightly Porous, Slightly Oxidized Surface	0.015 to 0.025 (0.038 to 0.064)	0.00
Slightly Porous, Oxidized Surface	0.025 to 0.040 (0.054 to 0.102)	+0.03 (+0.14)
Badly Pocked, Porous, Oxidized Surface	0.040 and above (0.102 and above)	+0.06 (+0.27)

*Putty Method
**Correction to standard tack coat of 0.18 gal/yd^2

(After Ref. 19)

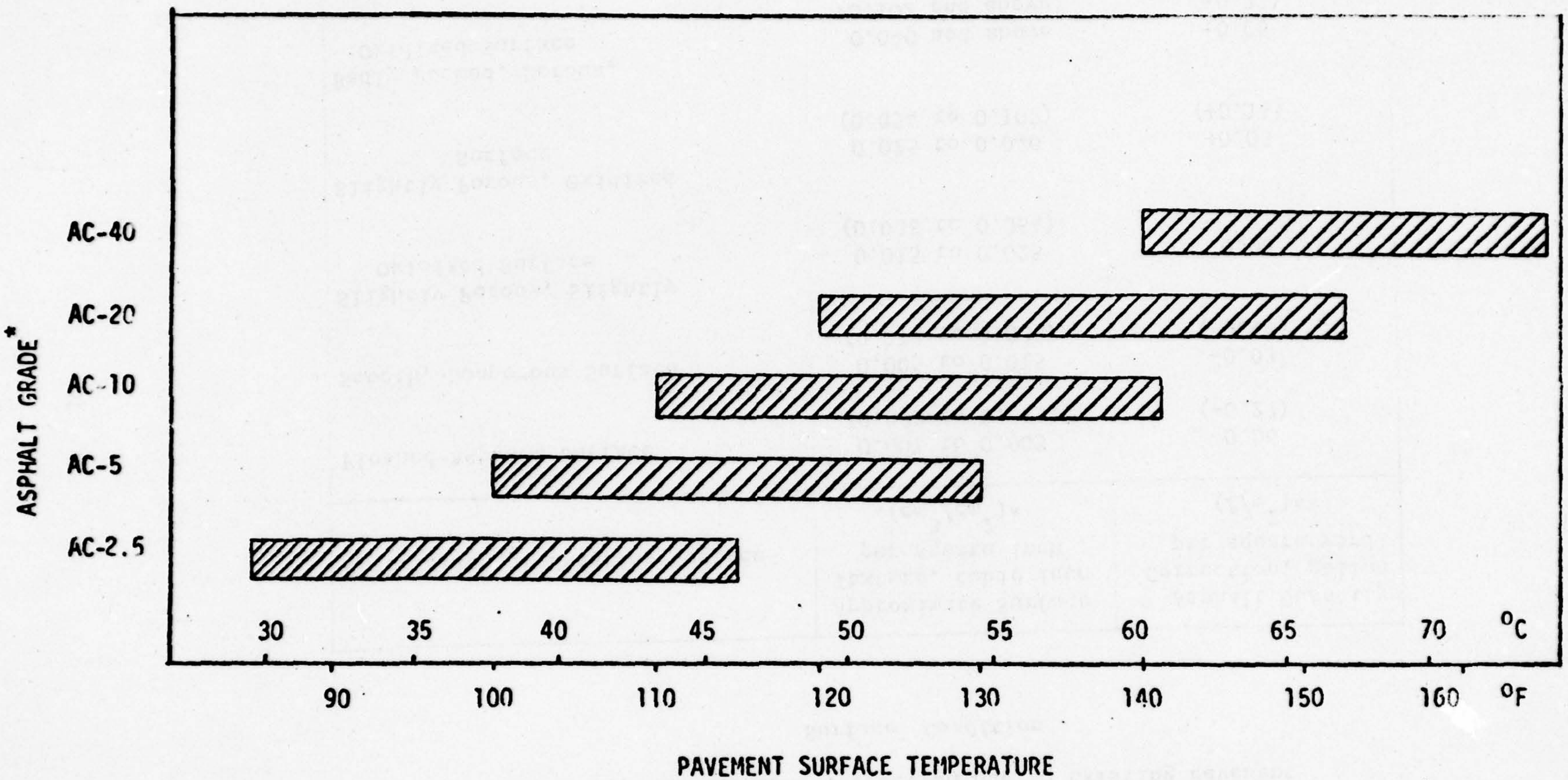


Figure 8

*(After AASHTO 226-73)

TABLE 4

SUGGESTED SPECIFICATIONS FOR ENGINEERING FABRICS
(OR PLASTIC FILTERCLOTH)
IN VARIOUS APPLICATIONS

PROPERTIES	APPLICATIONS				
	Crack Reflection	Erosion Control		Drains	Roads Over Poor Support Soils
		1'-	2'+		
Thickness, mils, min.	60	60	100	NA**	60
Water Permeability, gpm/ft.^{2}/min. (4" head)	200	300	200	300	200
Grab Tensile Strength lbs./min. Machine & Transverse	90	90	200	90	90
Grab Elongation, %, min./max. Machine & Transverse	20/70	15/70	15/60	15/70	15/70
Trapezoid Tear Strength lbs. min. Machine & Transverse	50	50	100	50	50
Energy to Puncture, ft. lbs. x10^{-2} minimum	NA	4.5	9.0	4.5	4.5
Elongation under 40% continuous load to stability hours, max.	NA	24	24	NA	24
Antiblinding Prop. Gradient Ratio, max.	NA	3	3	3	3

(After Ref. 20)

resistance was demonstrated in these tests, research to investigate the effectivenss in retarding reflection cracking is said to be necessary.

The following are some conclusions reached by the Federal Highway Administration concerning fabrics in overlay projects. They are quoted from the memorandum already mentioned.

> " The conclusions reached in 1976 regarding the effectiveness of Petromat when used with thin asphalt concrete layers are still valid for alligator-type cracking. Petromat covered with 1" of asphalt concrete performs about equal to a 2 inch mat without Petromat. In some cases this has provided a 100 percent increase in the life of the overlay.
>
> The performance of thicker lifts of asphalt concrete, 2" or more, over Petromat have not been adequately evaluated as yet because the life of 2" or more overlays greatly increases the life of the overlay without Petromat. Some projects are in progress but it may take 2 to 3 years before data is available for a decision.
>
> The performance of Petromat over asphalt concrete transverse thermal cracks has not been as promising as it has over the smaller block or alligator-type cracks. Projects such as Route 395 near Doyle in California and I-20 near Odessa, Texas show definite improvement, particularly in the early years. As the pavements become older and the asphalt harder, transverse cracks begin to develop but at a slower rate than the controls.
>
> The use of 2" or thinner layers over Petromat on portland cement concrete have not proved effective as a crack retardant. The one year old Georgia I-85 experiment indicates that at least 4" should be used as a cover with Petromat (6" without Petromat). These relationships, however, may change with additional years of service.
>
> Petromat continues to give good service when used as a maintenance tool under a chip seal coat in both Texas and California.
>
> Evidence developed to date in experimental projects indicated that the average performance of materials such as Mirafi, Petromat, or Structofors is quite similar.

When properly placed, Petromat provides a waterproof barrier between the surface and base.

The use of Petromat under open graded asphalt concrete shows promise of providing both a high skid resistance and a water barrier to the passage of water into the base.

Based upon the North Carolina US 70 project, there is very little difference in performance between continuous Petromat and and strips placed only over cracks."

It should be noted that these conclusions were based on results of highway pavements which differ from air carrier pavements in terms of subgrade classification, types of aggregates and gradation in base and sub-base, mix design and compaction requirements of the surface course, and repetition and intensity of wheel loads. However, they are not contradictory of airport pavement experience.

V. MODIFICATION OF OVERLAY MATERIAL PROPERTIES

Since environmental and traffic related forces cannot usually be manipulated, some attention has been directed at changing the material characteristics of the overlay with a view towards making it more ductile or more tolerant of certain types of strains. This has been effected, traditionally, by increasing the asphalt content of the mix with due regard to some undesirable effects that may arise, or by specifying softer grades of asphalt.

However, certain areas of industry have thrust upon pavement design and construction some types of additives that are either waste products or byproducts of the industrial process. Specifically, these are rubber from discarded tires and sulfur resulting from the mining of coal. The incorporation of these materials into the pavement overlay mixture has resulted in economies in the amount of asphalt cement required and has also increased stability, resilience and resistance to fatigue and low temperature cracking.

The search for ways of inhibiting reflection cracking of overlays has also led to field trials of expanded metal or wire fabric placed inside the overlay. No design criteria or means of analysis of stress in the composite overlay system exist and the reinforcement quantities have been determined by trial and error only. While it has not been standard practice to reinforce bituminous overlays with steel elements, some localities in the Southwest have reported success in reducing the size of reflection cracks.

Rubber Asphalt

Rubber asphalt has been used at Phoenix International Airport as a surfacing material over an asphalt base pavement that was showing signs of severe distress. The overlay which consisted in the addition of crumb rubber to the hot asphalt mixture was completed in 1966. Reports[24] state that this overlay has been performing excellently. Other reports of projects in Arizona where rubber asphalt surfaces have been used state that they have not only resisted fatigue cracking effectively but have prevented reflection cracking as well.

Much of the early work with rubberized asphalt was directed at finding a means of reducing fatigue type cracking and in the early 1960's highway agencies such as the Arizona Department of Transportation initiated projects to investigate the effects of up to 25 percent of ground recycled rubber in the asphalt mix. Field testing consisted of spreading a thin coating of the mixture over the cracked pavement and then covering it with chips to form a wearing course. The concept was applied to the prevention of reflection cracking by the Department in 1968 on an access road and on a service road and was found, after 8 years of service, to be very effective. Thermal and shrinkage cracks did reflect through the seal coat but they were narrow and few in number.

An improvement in the procedures associated with the use of asphaltic rubber was in the introduction of kerosene in small quantities to increase ease of application and wetting of the chips. Laboratory tests demonstrated that crumb rubber between the U. S. #25 and #40 sieves mixed with asphalt

and held at 190 degree C for 20 minutes increased in volume by 100 percent and became softer and more elastic. Good performance was believed to be due to the fact that individual particles coalesced with time and reacted in strain as continuous fibers. The addition of kerosene also caused a large drop in viscosity but the decrease had been seen in these observations to be temporary and the initial viscosity was regained in one to two hours.[25]

A great deal of laboratory investigations has been sponsored by Canadian highway authorities to determine the material characteristics of mixtures combining hot asphalt and vulcanized, as well as unvulcanized, rubber. These investigations reveal that there is a loss in Marshall stability in specimens so formed but that there is an increase in ductility, resilience and toughness over conventional asphaltic mixes.[26] It has been suggested that this change in material properties permits flexural and planar movements of the surface course without exceeding rupture strengths and is particularly desirable where low temperature cracking is a problem. Where reflection cracking is not a symptom of loss of structural support in the base pavement, this material has been known to be effective in reducing reflection cracking.

In other efforts undertaken to correct reflection cracking, some engineers specify that, in addition to a new asphaltic overlay, a coating of specially prepared composition be applied as a seal against the ingress of water and as a protector of the pavement against oxidation. Ruberized protective coating is commonly applied in the southeastern region of the

United States and to some extent in the Rocky Mountain region. The effectiveness of this procedure derives from the composition of the seal coat. In most cases, it consists of a coal tar pitch emulsion with equal quantities of water and a proprietary additive that will keep solid particles in suspension. Sand is added to the slurry in the amount of 16 lb. per gallon (1.9 kg. per litre) of coal tar. For greater skid resistance and workability, the sand is recommended to be of a size between the U. S. #30 and #20 sieves. The additive which keeps the sand in suspension consists of an acrylonitrille/butadiene copolymer latex having particle sizes of very small dimensions (400 to 1,000 angstroms or 4×10^{-6}cm to 10×10^{-6}cm).

Protective coatings 1/8-inch (3.2 mm) in thickness have rendered high skid resistances to newly overlaid pavements and by reports mu-meter readings vary from 0.5 to 0.7. The coating will help to prevent surface oxidation of asphalt pavements and inhibit softening or erosion due to spillage or drippage of petroleum derivatives. Manufacturers' recommendations require two applications of composition including sand and one without sand along with a 50 percent cutback in latex content. The effect of coatings of this type in reducing the reappearance of cracks is being investigated by test pavements at Miami International Airport. It is believed by the engineering contractors that the resilient coating of latex will render greater tolerance of temperature and load related strains and therefore will not crack as readily as an uncoated pavement.

Sulfur

Sulfur is a material in plentiful supply as a rsult of increased mining activity. Its utilization as a paving material has been investigated and, in fact, has been incorporated into asphalt concrete mixes in certain localities on an experimental basis. It has been found that small proportions of sulfur increase the Marshall stability of the mix but the effect on reducing reflection cracking is not known.

Much of the interest focused on sulfur as an asphalt extender has come from the major oil companies, the mining industry and federal agencies such as the FHWA and the Bureau of Mines. Some of the sponsored research have revealed that sulphur asphalt mixes have up to twice the Marshall stability of those with regular asphalt, with no loss in Marshall flow. The result of this improvement in material properties may therefore permit the use of lower penetration asphalts, lower mixing temperatures, lower quality aggregates, and reduced pavement thicknesses.[27] In addition to these benefits, it has been found that sulfur asphalt mixes impart a higher fatigue life to the pavement and are resistant to low temperature cracking.[28,29] Although many full scale tests have been conducted in Nevada, Texas and Michigan, only in some Provinces of Canada, do objectives specifically include monitoring for performance with respect to the prevention of reflection cracking. A one mile (1.6 km) test section in Winfield, Alberta that was constructed in 1974 is said to be performing excellently.

Steel Reinforcing in the Asphalt Concrete Overlay

A persistent problem of longitudinal cracking between new overlays and new construction has always occurred when a pavement is widened. As early as 3 decades ago, the Iowa State Highway Commission[30] investigated the effects on reflection cracking of welded wire fabric along the intersection between the old and new pavement, and delaying the application of the asphaltic overlay on the widened portion. It was concluded that the use of the fabric reinforcement did reduce the number of cracks appearing after 2 years. However, the pavements surveyed were not designed as experimental projects and the number of samples in any one category generally included at least two independent variables, or where only one variable was present the number of samples was too small to permit any definitive conclusion.

Some similarity in experience with wire fabric in asphaltic concrete overlays was also encountered in test sections at Lake City by the Florida State Road Department.[31] One of the objectives of a study in 1959 was to ascertain if steel reinforcement placed at mid-depth in the mat between old pavement and the widened section would inhibit the appearance of longitudinal cracks at the junctions. The conclusion was that while the presence of steel added a large cost to the project there were some beneficial effects and although some cracks did reflect they were small and had the same pattern as the mesh below. These were also small enough to enable the kneading action of traffic to close them thereby preventing ingress of water into the pavement. If there is enough material above the reinforcement, the effects of joint movement will

not be evident at the top surface of the mat. If there is insufficient thickness of material, then tensile strains will be apparent at the top surface and rupture of this surface will result depending on the fracture strength of the overlay.

Synthetic Fibres

Synthetic fibres, manufactured from nylon and polyester, have been introduced into hot mix bituminous material in an effort to reduce the incidence of reflection cracking. The most frequent usage of these materials appears to be by some municipal and state highway authorities when sections of city streets or highways are to be overlaid. No application of this method to general aviation airport pavements is on record. While nylon fibres have shown some effectiveness, it has proved to be too expensive and the use of synthetic fibres is now limited to polyester fibres only.

In 1976, the Delaware Division of Highways[23] initiated a study to determine the influence of different lengths of fibres in the hot mix on reflection cracking of bituminous overlays over portland cement concrete pavements. The four types of materials tested included nylon or polyester fibres of 0.25 or 0.50 inch (6.3 or 12.7 mm) in length and 0.00085 inch (0.02 mm) in diameter. Some of the test sections also included randomly cut fibres. (The research in Delaware profited from the results of prior research in Pennsylvania where the Township of Lower Merion introduced synthetic fibres into the asphaltic concrete mix for overlaying a city

street with a 1.0 inch, 2.54 cm, thick wearing course.) Conclusions were that fibres longer than 0.50 inch (1.3 cm) tended to clump together in the hot mix and that, for the wearing course, the bituminous mix should contain some fibres less than 0.50 inch (1.3 cm) in order to avoid clinging of the material to the screed. It was observed after 2 years' service that those sections of pavements containing fibres resisted reflection cracking more effectively than those without; also, best results could be obtained if the fibre concentration were held between 0.125 and 0.250 percent.

Increased Thickness of Overlay

Increasing the thickness of the bituminous overlay has been a successful measure against reflection cracking. The lower levels of the cross section of bituminous mats are less exposed to embrittling agents than the upper surface and, consequently, have better resilience to accomodate slab movements. With advancing age of the bituminous overlay there is increasing embrittlement and less tolerance of the existing pavement movements. An age is eventually reached where the whole cross section becomes so brittle that cracks begin to reflect upwards from the lower levels to the upper. It should, of course, be noted that the assumption here is that the material characteristics are depthwise uniform at the completion of construction. Typically, as noted in a previous report by the Federal Aviation Administration,[39] the greatest density of the mat will occur somewhere in the upper part of the mat and the fewer air voids that occur here will make this area most resistant to oxidation and embrittlement.

The attenuation of strain through the depth of the overlay at points where the mat spans an existing joint or crack must also be considered. Bituminous concrete, depending on the temperature and other factors, is an elastic, plastic, viscous material. At the interface next to the joint, maximum strain occurs and this diminishes through the height of the mat to a point where the strain may become zero. This transition of strain is more or less rapid depending on the material characteristics of the overlay. The more plastic the asphalt concrete the more rapid is the transition to zero. If there is enough material above this zero point, the effects of joint movement will not be evident at the top surface of the mat. If there is insufficient thickness of material, then tensile strains will be apparant at the top surface and rupture of this surface will result depending on the fracture strength of the overlay.

While many other factors must be considered as operating in a pavement, it has been observed that the best resistance to reflective cracking can be obtained by increasing the thickness of the bituminous mat. On highway ramps that are badly cracked from temperature related causes an overlay operation is usually initiated. Some of these cracks are seen to extend from one side of the pavement to the other. Sometimes, because of insufficient superelevation of the existing pavement, the overlay is made thicker towards the outside edge of the pavement. After about a year of operation, transverse cracks reflect from the low edge of the pavement halfway to the other side of the pavement. The increased thickness of the mat on the superelevated side does not permit the old crack to break through the bituminous overlay. In other pavements where

overlays have been installed, the areas with the greater mat thicknesses (deposited to maintain vertical alignment) have shown less reflective cracking than areas with thinner thicknesses of overlay. For normal airport construction where all of the FAA specifications relative to the construction of bituminous pavements have been satisfied, the thickness of overlay above which cracks do not reappear after a period of 3 years is about 5 inches (12.7 cm).

VI, OTHER OVERLAY TYPES

This report addresses reflection cracks that occur in dense graded bituminous mixes used as an overlay material. Several other types of overlays have been installed on airport pavements and highway facilities, and their performance with respect to reflection cracking should be mentioned. The most commonly used non-bituminous material for airport overlays is plain concrete and guidelines for their design are clearly defined in an Advisory Circular AC N. 150/5370-6C issued by the Federal Aviation Administration. And, with respect to superior performance in crack prevention and economies in cross section, plain concrete overlays do not compare favorably with continuously reinforced concrete (CRC). Fibrous concrete has recently been used, for purposes of criteria development, as overlay material on airport taxiways in the South and the West. Also, with respect to prevention of hydro-planing and increased friction and resistance, an open graded porous friction course has been shown to be superior to all the other types of overlays including dense graded asphaltic concrete overlays.

A great deal of interest has been directed to the use of these types in recent years and much research has been sponsored by various agencies of government. Some of the research relating to the performance of these materials and the incidence of reflection cracking will be discussed in the following pages.

Continuously Reinforced Concrete

Continuously reinforced concrete (CRC) is believed by many pavement engineers to be an effective overlay material for combating the incidence of reflection cracking. The initial cost of overlaying a cracked pavement with CRC is much greater than comparable work with bituminous material. However, experience with CRC construction at Jackson Municipal, Palmdale Air Force Base, Minneapolis International Airport, and Glenview Naval Air Station has shown that thicknesses of CRC of 8.0 inches to 14.0 inches (20.3 to 35.6 cm) have been very effective in preventing cracking. Wherever reinforced portland cement concrete slabs are laid for pavements, the kind of cracks observed are reported to be of small widths, evenly dispersed but in a random pattern. These cracks are those caused by volume changes that induce shrinkage and temperature stresses of rupture magnitude. A fine grid of reinforcing bars or effective frictional resistance at the interface between the pavement and overlay tends to provide mechanical restraints that reduce movements and inhibit cracking. This explains why rehabilitation work with this material requires the design of a slab of such depth and strength as not to be considered as an overlay.

In 1971, the FAA, Corps of Engineers and the Air Force Weapons sponsored research to evaluate the performance of CRC airport pavements and to develop design procedures for pavements and overlays. The criteria that were developed were based on a load related mode of distress and environmentally induced distress was not addressed in the methodology. It was suggested that additional research could provide adjustment

factors to account for environmentally related distress in these pavements. The application of this methodology has permitted the design and construction of CRC pavements and overlays that have performed without failure and it has been reported that spalling of concrete (thereby exposing reinforcing bars) and not reflective cracking has been the most frequent cause of concern in the use of these pavements. It has been reported by engineers at the Naval Air Station at Patuxent, Maryland where a great deal of pavements has been overlaid with bonded CRC that in many cases reflection cracks have been minimal on pavements as much as 8 or 9 years old.[33]

Fibrous Concrete

The use of fibrous concrete as an overlay material has been studied in some depth by the Corps of Engineers on behalf of the Federal Aviation Administration. One of the studies was conducted on a taxiway at Tampa International Airport in Florida. Although the purpose of research was to develop design criteria for overlay design in fibrous concrete, the investigations provided guidelines on its effectiveness as a construction material and for preventing reflection cracking.[34]

The existing pavement was a severely deteriorated section of taxiway that was constructed in 1965. It consisted of 12.0 inches (30.5 cm) of portland cement concrete over 3.0 inches (7.6 cm) of a preparation described as 50 percent crushed limerock and 50 percent sand. The subgrade was granular to a depth of at least 28 inches (71.1 cm). The cause of this rapid deterioration was attributed to a combination of

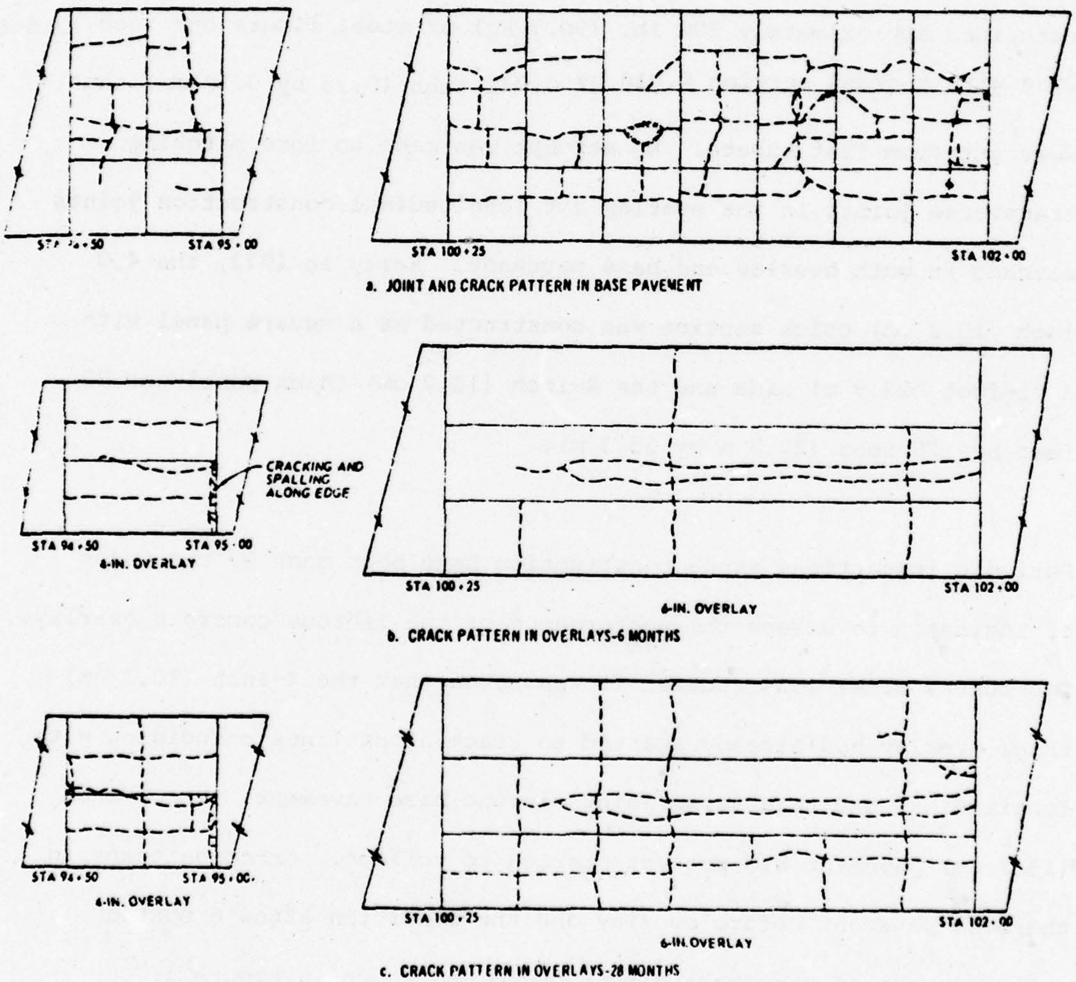
slowly moving traffic, warping, friction stresses and fatigue. A fatigue analysis made in 1972 indicated that the remaining useful life of the pavement was only 3.3 years.

A plan was therefore formulated to overlay the taxiway with 4.0 inches (10.2 cm) of fibrous concrete and 6.0 inches (15.2 cm) of the same material in another area. Each cubic yard (cubic meter) of concrete contained approximately 200 lb. (90.7 kg) of steel fibers one inch (2.5 cm) long with a cross section 0.010 by 0.022 inch (0.25 by 0.56 mm) that were cut from flat sheets. No attempt was made to form matching transverse joints in the overlay but longitudinal construction joints matched in both overlay and base pavement. Early in 1972, the 4.0 inch (10.2 cm) thick section was constructed as a square panel with a 75-foot (22.9 m) side and the 6-inch (15.2 cm) thick panel was 75 feet by 175 feet (22.9 m by 53.3 m).

Periodic inspections since construction have been made by the Corps of Engineers to assess the performance of the fibrous concrete overlays. Two months after construction it was noted that the 4-inch (10.2 cm) thick overlay had already started to crack along lines coinciding with longitudinal and transverse joints in the base pavement. The 6-inch (15.2 cm) pavement had not yet started to reflect. Crack patterns in the base pavement before overlay and the condition after 6 months and 28 months of service are reproduced and shown in Figure 3.

In April 1979, the most recent inspection revealed that about 75%

of the original cracks reappeared in the 4-inch (10.2 cm) overlay and about 50% in the 6-inch (15.2 cm) overlay. It should be observed that the 4-inch thick test section was placed at a taxiway exit ramp intersection and was subjected to shearing forces from turning aircraft that were never developed at the 6-inch (15.2 cm) test section located further up the taxiway. How much this difference in loading pattern was influencing load related reflection cracking is not known.



Joint and Crack Pattern in Base Pavement
and Fibrous Concrete Overlays at Tampa International Airport

Figure 9
(After Ref. 35)

Porous Friction Course

The inclusion of a Porous Friction Course (PFC) as part of an overlay operation for airport pavements has been increasing in this country since its first application in Great Britain in 1962. Early test sections were constructed at Kirtland Air Force Base in New Mexico, Pease Air Force Base in New Hampshire and at several civil airports including those at Nashville, Salt Lake City, Hot Springs and Denver to determine construction procedures and field performance. PFC is an open graded asphaltic concrete material that permits the passage of water to an impervious surface below and imparts very high skid resistance to the pavement over which it is laid.

Research conducted by the Corps of Engineers[37] has, however, demonstrated some succeptibility of this overlay material (generally about 1-inch, 2.5 cm, thick over the usual asphalt concrete overlay) to pop-outs due to freezing and thawing, and to raveling and reflection cracking over underlying longitudinal and transverse joints, after only a few months of service. Later investigations by the Naval Civil Engineering Laboratory[38] into the design, construction and performance of PFC, concluded that this material will not prevent reflection cracks from developing when it is laid over impaired surfaces but has advantages over conventional bituminous overlays such as requiring less rolling and lower mixing temperatures.

VII. CONCLUSIONS

Consideration of the data collected during the course of this report suggests that most of the field tests relative to the various efforts to prevent reflection cracking are extensions of maintenance operations and, as such, proper design of the experiments is subordinated to such factors as opening the pavement to traffic and maintaining grades. In the main, the variables associated with the material properties of the overlay, the total cross section of the pavement, subgrade bearing strength, geometry, traffic and temperature transience are not quantified. Installation duties are mostly performed by field workers who are often unskilled and lacking in knowledge of technical reporting techniques and experimental design. Observation of the performance of the overlay is generally conducted on a casual basis, there being no national standard basis that would enable two independent observers to report the same performance. The result of unscientific documentation (or lack of any) is a confusing set of data that cannot be used to secure any prescribed effect.

It is understandable that efforts to reduce reflection cracking should be initiated by maintenance personnel. They experience a recurring problem that requires annual expenditures of large sums of money to repair pavement surfaces. But, large sums of money are also being disbursed on materials that susposedly have effectiveness in reducing the number of reflected cracks. Systematic research effort on the most promising of these efforts could yield definitive relationships between all the variables involved

and reduce the number of meaningless tests. At the present time, and from the data available, it is apparent that the only repeatable result is that for any set of conditions, thicker asphaltic concrete overlays are more resistant to reflective cracks than thinner ones; also, overlays on asphaltic base pavements are more crack resistant than on jointed concrete pavements, all other factors similar. These are, however, qualitative results and properly executed research could have made quantification possible.

Theoretical and laboratory studies, under Government and industrial sponsorship, are underway to understand the mechanics of reflection cracking and to establish criteria for design of overlay systems that are resistant to reflection cracking. However, they are still in their early stages and touch only a few of the vast number of variables associated with the pavement system. Mathematical modeling of certain restricted systems have yet to be field validated and observed by meticulous researchers.

It has been estimated that in 1979, 350 million tons (318 Gg) of asphalt concrete will be laid for pavements and about 10 percent will be for airport pavements. A large proportion of this sum will fund overlay of badly cracked pavements (some of which had previously been overlaid). It would appear that any proven measure that can inhibit reflection cracking and extend the life of these pavements, even if only by a small percentage, would make a large part of these annual expenditures unnecessary.

VIII. RECOMMENDATIONS

In order to develop dependable criteria for methods to reduce or prevent reflection cracking of bituminous overlays, the following actions are recommended:

1. Consideration of all of the factors operating on a pavement system and their inter-relationships must first be undertaken.

2. Field installation of the various methods, recording of material properties and geometry, and periodic performance evaluations should only be performed by qualified personnel.

3. A "universal" condition survey methodology must be adopted in order to eliminate observer bias.

4. Claims of the effectiveness of any device or product have not been verified under all conditions. At present, there is no basis for guarantees of performance and therefore warranties should not be accepted.

5. While the factors affecting the phenomenon of reflection cracking are complex and involve changes in material properties with time, load and temperature, definite advances are being made in sponsored research using elastic theory. Continued research is needed and should be supported as a first step before more elaborate analytical formulations are attempted.

6. Airport pavement engineers should be advised that "cost effectiveness" studies of the various methods for reducing reflection cracking may not be of value if the degree of effectiveness of these methods cannot be predicted.

IX. SELECTED REFERENCES

1. Majidzadeh, K. and G. G. Sukarieh, "Analytical Modeling and Field Verification of Thermal Stresses in Overlay," Transportation Research Record No. 632, 1977, p. 44.

2. "The Fracture Mechanics Approach to Reflection Cracking," Cooperative HPR Study, Ohio State University.

3. Majidzadeh, K., Use of Theory of Fracture Mechanics Crack Propagation in Flexible Pavements, Paper Presented at Second Workshop on Mechanistic Pavement Analysis Techniques, FHWA 1977.

4. Treybig, H. J. et al, Overlay Design and Reflection Cracking Analysis for Reflection Cracking, Vols. 1 & 2, Federal Highway Administration, FHWA Report FHWA-RD-77-67 dated 1977

5. Velz, P. G., "Effect of Pavement Breaker Rolling on Crack Reflectance in Bituminous Overlay", Highway Research Record No. 11, Highway Research Board Publication, 1963.

6. Lyon, J.W., "Slab Breaking and Seating on Wet Subgrades with Pneumatic Roller," Highway Research Record No. 11, Highway Research Board Publication, 1963.

7. Stackhouse, J.L., "Preparing Old Pavements for Resurfacing with 50 Ton Compactor," Proceedings, Highway Research Board, Vol. 38, 1959.

8. McCullagh, F. R., Reflection Cracking of Bituminous Overlays on Rigid Pavements, Special Report No. 16, Engineering R&D Bureau, N. Y. State Department of Transportation, 1973

9. Kher, R., Road Test to Determine Implication of Preventing Thermal Reflection Cracking in Asphalt Overlays, Transportation Research Record No 632, Transportation Research Board, 1977, p. 37.

10. Way, G., Prevention of Reflective Cracking in Arizona Minnetonka-East (A Case Study), Report No. 11, HPR-1-13(224) Arizona Department of Transportation, 1976.

11. Engineering Brief No. 4, Federal Aviation Administration, Office of Airports Programs, 1975.

12. Vicelija, J. L., "Methods of Eliminating Reflection Cracking in Asphalt Concrete Resurfacing Over Portland Concrete Pavements." Proceedings, Association of Asphalt Paving Technologists, Volume 32, 1963.

13. Airport Pavement Design and Evaluation, Federal Aviation Administration Advisory Circular, AC No. 150/5320-6C.

14. Asphalt, Asphalt Institute, 1973

15. Construction Leaflet No. 16, Asphalt Institute, Dec. 1975.

16. Steward, J. et al, Guidelines for Use of Fabrics in Construction and Maintenance of Low-Volume Roads, Reprint FHWA-TS-78-205, 1977

17. Jackson, Ralph D., Preventive measures for Reflective Cracking of Asphalt Concrete State of the Art, Preliminary Report, U. S. Army Corps of Engineers, Vicksburg, Mi, March 1979.

18. Donnelly, Dennis E., et al, Reflection Cracking in Bituminous Overlays, Report No. FHWA-CO-RD-76-6, Dec. 1976.

19. Epps, Jon A. and J. W. Button, Mirafi Tack Coat Requirement for Asphalt Overlays, Texas Transportation Institute, Interim Report RF 3424-1

20. Parks, Robert M., Engineering Fabrics: Their Uses, Evaluation Methods and Specifications.

21. Majidzadeh, K., A Laboratory Investigation of the Use of Petromat for Optimization of Pavement Performance, Resource International Inc., Report dated 1976

22. Majidzadeh, K. et al, Verification of Fracture Mechanics Concepts to Predict Cracking of Flexible Pavements, Federal Highway Administration, Report No. FHWA-RD-73-91 dated 1973

23. Martinez, B.P. et al, "Synthetic Fibers Reduce Reflection Cracking" Public Works City, County and State, Public Works Journal Inc., April 1979 p. 55.

24. Rubber Asphalt Binder for Seal Coat Construction, Implementation Package 73-1, Report on Work by Charles H. McDonald, Phoenix, Az., February 1973.

25. Morris, Gene R., Asphalt-Rubber Stress Absorbing Membranes: Field Performance and State of the Art, Transportation Research Record No. 595, 1976.

26. Piggott, W. et al, "Improved Hot Mix Asphalts Containing Reclaimed Rubber," Proceedings, Association of Asphalt Paving Technologists, 1977.

27. Direct Substitution of Sulfur for Asphalt in Paving Materials, Bureau of Mines Report of Investigations, 1978, No. RI 8303.

28. "Sulphur- Asphalt Technologies Near Commercialization," Sulphur Institute, Sulphur Research & Development, Volume 1, 1978.

29. Meyer, R. P. et al, "Temperature Succeptibility Evaluation of Sulphur-Asphalt Mixtures," Proceedings of Association of Asphalt Paving Technologists, Volume 46, 1977.

30. Boring, J. E. and Myers, M., "Investigation of Longitudinal Cracking through Asphaltic Concrete Resurfacing," Proceedings, Highway Research Board, Vol. 38, 1959.

31. Smith, L. L. and Gartner, W., "Welded Wire Fabric Reinforcement for Asphaltic Concrete," Highway Research Board Bulletin 322.

32. Harvey, Gary G., Design and Construction of Continuously Reinforced Concrete Airport Pavements, U. S. Army Engineer Waterways Experiment Station, Report No. FAA-RD-74-37, 1977.

33. McGrath, Frank, Oral Communication on the Use of Bonded Continuously Reinforced Concrete Overlays, Naval Air Station, April 1979.

34. Parker, F., Construction of Fibrous Reinforced Concrete Overlay Test Slabs, Tampa International Airport, Florida, U. S. Army Engineer Waterways Experiment Station, Report No. FAA-RD-72-119, 1972

35. Criteria for Airport Pavements Final Summary Report, U. S. Army Engineer Waterways Experiment Station, Report No. FAA-RD-74-35, 1976.

36. Sample Specification for Engineering Fabrics, U. S. Department of Transportation Publication, FHWA-TS-78-211, dated 1978

37. White, Thomas D., Porous Friction Surface Course, Report No. FAA-RD-73-197 Federal Aviation Administration, 1973.

38. Tomita, H. and J. B. Forrect, Porous Friction Surfaces for Airfield Surfaces, Report No. AFWL-TR-74-177, Naval Civil Engineering Laboratory, 1975.

39. McLaughlin, Aston L., Field Compaction of Bituminous Airport Pavements FAA, Report No. FAA-RD-77-42.

APPENDIX A

Summary of Physical Properties

Of Fabrics Commonly Used In Overlay Projects

(Reproduced From Report FHWA No. TS-78-205, dated 1977)

Physical Properties

MANUFACTURER OR SUPPLIER	CELANESE FIBERS MARKETING COMPANY	DU PONT TEXTILE FIBERS DEPARTMENT	CROWN ZELLERBACH CORPORATION		
Trade Name	Mirafi 140	Typar	Fibertex	Fibertex	Fibertex
Construction	Nonwoven Continuous Filament	Nonwoven Spunbonded Polypropo-lene	Nonwoven, Spunbonded Polypropolene, Needle Punched		
Thickness, mils	30	15	125	190	250
Weight, oz/yd^2 ($^{gm}/_{m^2}$)	4 (140)	4 (140)	9.4 (320)	12.4 (420)	17.7 (600)
Equivalent opening size (EOS) U.S. Standard Sieve	100				
%Open Area					
Strip Test, 1" Wide ASTM D-1682 Warp/Fill (lb/in)	25		75	100	150
Elongation, %					
Grab Test ASTM D-1682 Warp/Fill (lb/in)	120	160/160	125	150	250
Elongation, %	130	60/65			
Oregon State U. Ring Test, lb/in Wet/Dry @ 12 in./min.	35.0/50.0	60.0/60.0	90.0/100.0	170.0/170.0	
% Elongation Wet/Dry	115.0/75.0	90.0/80.0	200.0/150.0	375.0/330.0	
Burst, lb ASTM D751	120	190			
Seam Strength					
Abrasion Resistance lbs. after 1000 cycles					
Width, Ft.	14.75	12.5 & 15.5	17.3	17.3	17.3
Length, Ft.	328	300,900,3000	180	140	100

MANUFACTURER OR SUPPLIER	ERCO SYSTEMS, INC.		PHILIPS PETROLEUM COMPANY		MENARDI-SOUTHERN DIVISION OF U.S. FILTER CORP.
Trade Name	Nicolon 66411	Nicolon 66301	Petromat	Supac	Monofilter
Construction	Woven Polypropo-lene	Woven Polypropo-lene	Nonwoven Polypropo-lene	Nonwoven Polypropo-lene	Woven Polypropo-lene
Thickness, mils				40	20
Weight, oz/yd^2 (gm/m^2)			4.2 (140)	4.1 (140)	7 (245)
Equivalent opening Size (EOS) U. S. Standard Sieve	30				70
% Open Area	36				
Strip Test, 1" wide ASTM D-1682 Warp/Fill (lb/in)	186/150			100	350/275
Elongation, %	23/11			80	27/29
Grab Test ASTM D-1682 Warp/Fill (lb/in)			50/50		
Elongation, %			70/70		
Oregon State U. Ring Test, lb/in Wet/Dry @ 12 in/min.				68.0/60.0	
% Elongation Wet/Dry				101.0/50.0	
Burst, lb.	437			160	545
Seam Strength, lbs/in	90				
Abrasion Resistance, lbs. after 1000 cycles					
Width, ft.			6 or 12	15	
Length, ft.			300	300	
				K = 6×10^{-2} cm/sec.	

(continued)

MANUFACTURER OR SUPPLIER	MONSANTO TEXTILES COMPANY				
Trade Name	Bidim C 22	Bidim C 28	Bidim C 34	Bidim C 38	Bidim C 42
Construction	Nonwoven, Spunbonded polyester, Needlepunched				
Thickness, Mils	75	95	109	114	188
Weight, oz/yd^2 (gm/m^2)	4.5 (150)	5.9 (200)	9.6 (325)	12.4 (420)	19.4 (657)
Equivalent opening Size (EOS) U. S. Standard Sieve	80	80	80	80	80
% Open Area					
Strip Test, 1" Wide ASTM D-1682 Warp/Fill (lb/in) Elongation, %					
Grab Test ASTM D-1682 Warp/Fill (lb/in) Elongation, %	110	213	234	290	582
Oregon State U. Ring Test, lb/in Wet/Dry @ 12 in/min. % Elongation Wet/Dry	60.0/60.0 44.0/44.0	84.0/84.0 63.0/63.0		130.0/130.0 50.0/50.0	
Burst, lb. ASTM-D751	225	397	422	503	864
Seam Strength					
Abrasion Resistance, lbs. after 1000 cycles					
Width, ft.	13.8-17.4	13.8-17.4	13.8-17.4	13.8-17.4	13.8-17.4
Length, ft.	990	990	990	990	462

(continued)

MANUFACTURER OR SUPPLIER	CARTHAGE MILLS, INC.			ADVANCE CONSTRUCTION SPECIALTIES	
Trade Name	Filter-X	Poly-Filter X	Poly-Filter GB	LECC Type A	LECC Type B
Construction	Woven, Vinylidene Chloride	Woven, Polypropolene	Woven, Polypropolene	Woven, Polypropolene, Monofilament yarn	Woven, Polypropolene Monofilament yarn
Thickness, Mils	15	16.8	26	17	22
Weight, $^{oz}/_{yd^2}$ ($^{gm}/_{m^2}$)	11.6 (390)	7.2 (244)	6.6 (225)	7.2 (244)	6.3 (213)
Equivalent opening Size (EOS) U. S. Standard Sieve	100	70	40	100	40
% Open Area	4.6	5.2	24.4	4.3	26
Strip test, 1" wide ASTM D-1682 Warp/Fill (lb/in)	206/113	388/257	208/202		
Elongation, %	22/27	22/27	24/17		
Grab Test ASTM D-1682 Warp/Fill (lb/in)	200/110	380/220	200/200	399/244	280/232
Elongation, %				33/33	40/42
Oregon State U. Ring test, lb/in @ 12 in/min. % Elongation					
Burst, lb	268	542	625	528	528
Seam strength	80	195	160	198	198
Abrasion resistance, lbs. after 1000 cycles	57/9	100/70	161/162		
Width, ft.	6-84 in 6' mult.	6-84 in 6' mult.	6-84 in 6' mult.	6-84 in 6' mult.	6-84 in 6' mult.
Length, ft.	50 - 1200	50 - 900	50 - 1200		

(continued)

MANUFACTURER OR SUPPLIER	STAFF INDUSTRIES			
		PERMEALINER		
Trade Name	M-1192	M-1195	M-1196	M-1197
Construction	Woven Polypropylene			
Thickness, mils				
Weight, oz/yd^2 ($^{gm}/_{m^2}$)	6.8 (236)	7.2 (252)	7.2 (252)	7.2 (252)
Equivalent opening size (EOS) U. S. standard sieve	30-50	70-100	50-100	30-100
% Open Area	9-15	4-10	4-15	4-20
Strip test, 1" wide ASTM D-1682 Warp/Fill (lb/in)	350/240	400/280	350/220	325/210
Elongation, %	36/26	34/32	34/32	34/32
Grab Test ASTM D-1682 Warp/Fill (lb/in)				
Elongation, %				
Oregon State U. Ring test, lb/in @ 12 in./min. % Elongation				
Burst, lb ASTM-D751	465	510	500	450
Seam Strength				
Abrasion resistance, lbs. after 1000 cycles		80	80	75
Width, ft.				
Length, ft.				

(continued)

MANUFACTURER OR SUPPLIER	Staff Industries		Gulf States Paper Corp.	Advance Construction Specialies	
Trade Name	Permealiner		Hold/Gro	Polyfelt TS 300	
Construction	Needle-Punched		Polypropylene yarn with paper filler	Nonwoven	
Thickness, mils				127	
Weight, oz/yd^2 ($^{gm}/_{m^2}$)	4 (140)	8 (280)	2.8 (98)	7.8 (273)	
Equivalent Opening size (EOS) U. S. standard sieve	120	100			
% Open Area					
Strip Test, 1" wide, ASTM D-1682 Warp.Fill (lb/in)	80/60	150/140			
Elongation, %	20/30	12/11			
Grab Test ASTM D-1682 Warp/Fill (lb/in)				227	
Elongation, %				101	
Oregon State U. Ring Test, lb/in @ 12 in/min. % Elongation					
Burst, lb ASTM-D751	143	400			
Seam Strength				236	
Abrasion resistance, lbs. after 1000 cycles					
Width, ft.	15	4.75	5 & 10	Multiples of 8.17	
Length, ft.			360	787	

(continued)

APPENDIX B

Summary of Field Installations

of Fabric

To Reduce or Prevent Reflection Cracking

(Reproduced from Memorandum FHWA No. HHO-31,
dated March 9, 1978)

SUMMARY OF EXPERIENCE WITH "PETROMAT" AS A TREATMENT FOR REFLECTION CRACKING IN BITUMINOUS OVERLAYS

STATE	Description of Installation	Date of Construction	Conclusions - Recommendations - Comments
Arizona	I-40 Winslow, High Desert. 5,000 foot elevation. Annual precitation < 8 inches Overlay: 1 1/4 inches AC plus 1/2 inch AC Finish Course. Cost per square yare (Petromat): ADT = 10,000 Temperature range 0° - 100°F	6-72	Petromat ranked 6th in terms of percent reflection cracking appearing by 1975. (12 percent vs. 17 percent for control sections). Reflected cracks were predominantly longitudinal. "Cracking probably due to a lack of balance between strength properties of Petromat and AC. For Petromat to work it should be used in conjunction with the thinnest most flexible surfacing, perhaps a seal coat." Ride very good; rut depth shallow; deflection changed little with time. No maintenance required on the sections as of late 1975. Rubber-asphalt seal coat applied over entire project in June, 1976.
California	1. Doyle, 02-LAS-395 Susanville 02-LAS-36 0.08' AC + Petromat	1. 8-72	1. Annual Temperature range -23 - 101°F. Annual Precipitation 14.5 inches. Petromat section has 2 longitudinal cracks (not reflection). Reflection cracking 6 percent. Control: 27 percent. Janesville sections: Petromat patches have reflected cracks after 39 months. No difference between control and fabric sections after 4 years.
	2. Colfax - 03-Pla-80 0.20' AC + Petromat	2. 7-74	2. Too early for valid conclusions. Annual temperature 20-106°F. Precipitation 47 inches.
	3. Long Beach - 07-LA-1 0.10'. 0.15', 0.20' AC over Petromat	3. 1-73	3. Stone dust and Petromat placed over both AC and PCC pavements. Joints in PCC reflecting through 0.10' AC sections. Annual temperature range: 33-111°F. Annual Precipitation 13 inches. Too early to evaluate other sections.
	4. Riverside 08-Riv.-15 0.08' AC + Petromat 0.35' AC + Petromat	4. 9-72	4. Annual Temperature range: 23-115°F. Annual Precipitation 11 inches. In 0.08' AC sections with Petromat, cracks have reflected, however, less pumping evident and cracks are hairline. Control section failed and was overlaid in April 1976. "Based on performance to date it is estimated that the use of Petromat has extended the life of the 0.08 foot blanket on this project by 2 1/2 to 3 years."
	5. VISTA 11-SD-78 0.08' AC + Petromat	5. 12-72	5. Annual temperature range: 26-105°F. Annual Precipitation 11 inches. Alligator cracking has reflected through the overlay at several locations in the control sections plus evidence of pumping. A very minimal amount of cracking in the Petromat section. "Performance to date indicates that Petromat has extended the service life of this 0.08 foot blanket on this project by more than 2 years."
	6. BRAWLEY 11-IMP-115 0.10' AC + Petromat 0.20' AC + Petromat	6. 4-74	6. Annual temperature range: 25-120°F. Annual Precipitation 2.3 inches. Two small cracks have been observed in the Petromat sections. Too early for conclusions to be drawn.

STATE	Description of Installation	Date of Construction	Conclusions - Recommendations - Comments
			GENERAL: Cores through cracked pavement showed that cracks extended through the overlay but not through the Petromat. Petromat layer "may continue to act as an effective water barrier even though cracks appear in the overlay." Water permeability tests on cores "indicated that the Petromat layer is performing as a water barrier." "The results of the Petromat with overlay appear more promising when placed on alligator cracked pavements as opposed to transversily and longitudinally cracked pavements. Our experience to date indicates that Petromat is, in general, more effective in retarding fatigue cracking (load associated) than it is in retarding thermal cracking (non-load associated). Also, Petromat installations in moderate or warm climates appear to perform better than those in the cold environments."
Colorado	I-70 West Central Colorado Pavement badly cracked prior to overlay treatments. Original roadway built in 1963 as first stage. 3 inches AC surface. Subgrade was Mances Shale. No data on annual temperature range or precipitations.	10-71	Although much of the project required extensive leveling courses of variable thickness, the Petromat sections (2) did not. Petromat sections performed best based on average amount of reflection cracking. Cracks in old pavement were hand poured with sealant prior to placing Petromat. "High cost of the Petromat fabric makes this material somewhat less desirable for marginal cracking problems and low traffic roadways. This treatment is recommended for use in high traffic areas and on severely cracked roadways." By 1976 only 1 percent of the original cracks had reflected through the overlay in one Petromat section and none in the other. The control sections had 88 percent and 61 percent cracks reflected by 1976. Both control sections had significant thicknesses of leveling course, as well.
Florida	I-75 PAYNES PRAIRIE. Original roadway 3" asphalt surface over 10" limerock base over 12" lime stabilized subgrade. Test sections were 1,000 feet in outside lane only. Prior to test sections a 1" level course was placed on the old pavement. ADT = 8-9,000	4-71	Cores were taken at random over cracks in the overlay to determine whether or not the cracks were reflective. "Cracks that stopped short of the old pavement were considered to be non-reflective and cracks that appeared in the surface and continued through the old pavement were considered to be reflective." Test section evaluations were completed in January 1977. Cracking measured in 1970 before overlay was 1,590 square feet while cracking measured in June 1977 was 1,102 square feet. This was still the best section. Cracking in the Petromat section in January 1977 based on three cores indicated non-reflective cracks. Conclusion: use of Petromat for reducing reflective cracking "appears to have some merit. However, a cost-benefit ratio study should be made and compared to the other methods that appear to be effective; namely, the Extra Thickness Section, the Open-Graded Section, and the Control Section." As of January 1977 cracking in the Petromat section was described as "fine disconnected hairline cracks occurring over an area" with some of those cracks 1/16-1/8 inch in width and some alligator cracks oriented longitudinally in the outer wheelpath.

STATE	Description of Installation	Date of Construction	Conclusions - Recommendations - Comments
Iowa	Iowa Highway 89 - Original pavement was a 10" PCC - 20 feet wide built in 1942. Widened to 24 feet in 1971 with asphaltic concrete and overlayed. Experimental fabric sections were included. The overlay was 3 inches of asphaltic concrete. 5 percent trucks with an ADT of about 2,500 in 1976.	1971	All cracks in the existing pavement were cleaned and filled with an asphalt mix. Petromat covered 24 foot width in rural section. In urban area the fabric was not placed across the existing crack between the pavement and the curb and gutter section. Annual crack surveys were conducted for 5 years. The widening joint and transverse cracks were the only reflection cracking considered in the rural area. After 5 years there was no reflection cracking over the widening joint in the Petromat section while 33 percent of the widening joint had reflected through the overlay. Transverse reflected cracking over Petromat was about 16 percent after 5 years in the rural section and about 40 percent in the urban section. In the rural section the control had reached about 50 percent reflected cracks and about 60 percent in the urban section. CONCLUSIONS AND RECOMMENDATIONS: Fabrics (2 other used as well) reduced reflection cracking when compared to the control. Reflection cracking over the widening crack was nearly eliminated using fabrics. Parameters for future research: (a) greater truck count (b) fabric width necessary to control widening crack reflection and (c) whether cracks would be generated from the edges of the fabric when placed as a strip over the widening joint.
Louisiana	Northbound lanes of U.S. 61. Asphalt overlay, 3 1/2 inches on old PCCP. Before Petromat placement all joints and cracks were swept clean and those over 1/4 inch wide were filled with sand and cemented with an asphalt emulsion. Petromat was placed in 20 inch wide strips over joints and cracks. ADT per lane: 6,500	3-71	No significant difference is visible between the control section and the Petromat section after 3 1/2 years. CONCLUSIONS: The 2 fabrics used (Cerex was the other) have neither eliminated reflection cracks nor when compared to the control sections reduced the degree of cracking up to the time of report (3-75). Both fabric test sections are performing in a structural manner similar to their control sections. Control and test sections are considered acceptable from a structural standpoint; cracks are still only blemishes.
South Dakota	U.S. 12 Corson County - Roadway graded in 1965 was not surfaced until 1968. Located in Pierre Shale area. 3 foot wide strips were centered on selective cracks of existing pavement. 17 strips were placed on a 1,000 foot section. A maintenance overlay was placed over the test section. The overlay was bladed into place and in places only 1/2 inch was put down when 2 inches were planned. OBJECTIVE: Place fabric to seal off any rain or melt waters that enter through large cracks in the overlay.	1971	Cracks reflected early where the overlay was only 1/2 inch. Severe spalling occurred in these same areas. Maintenance forces filled spalled areas with coarse sand slurry mix. During winter cracks in overlay opened to 1/4 inches while crack under Petromat opened at least 3/4 inch. During summer the slurry mix over cracks closes. A series of holes were bored in areas of strips and areas of open cracks to determine moisture contents. Based on data from 12 moisture test locations the moisture content under Petromat was 3 percentage points below moisture contents under open cracks in a 1974 survey. Petromat is effective in reducing the reflective cracking with a reduction in water infiltration. The extreme temperature differential (not reported specifically) has not caused the membrane (Petromat) to separate at the cracks and has remained intact throughout the 3 year observation period. RECOMMENDATIONS: All cracks be sealed with Petromat strips prior to overlay: the overlay mat be not less than 3 inches and any reflection cracking that occurs be sealed with a soft sand slurry.

STATE	Description of Installation	Date of Construction	Conclusions - Recommendations - Comments
Texas	I-20 between Odessa and Midland extensively cracked in the outside lane. Three different sections were constructed using Petromat: 1. Fabric under 1 1/4 inches of HMACP 2. 1 1/4 inches HMACP on existing pavement followed by fabric and a seal coat surface. 3. Fabric on the existing pavement with an emulsion seal coat over if for the surface.	1. 3-74 2. 3-74 3. 7-73	February '76 report shows percent reflection cracking as follows: 1. One percent; 2. None; 3. 77 percent Tentative Conclusions: Section 2 was one of the best test sections and appeared to be a practical method with which to achieve reduced maintenance. More extensive use has been made of Petromat since this test project; on I-20 near Pecos. Placed during mid-1976 it is composed of a surface treatment on the existing surface followed by an AC prime, Petromat and an open graded asphalt friction course. Original plans were for a 3 inch asphaltic concrete overlay. Petromat is equivalent in cost to 1 1/4 inches of hot mix.
Virginia	1. Route 460 - Sussex County - This is a PCCP with 30 foot joint spacing. 3 foot wide strips of Petromat were placed over 99 joints. About 1 1/4 inches of asphalt overlay was placed over the fabric. 2. I-95 near Pentagon. Strips over joints in PCCP.	1. 8-71 2. 7-72	1. Measurements were made between gage points every month for 30 months to check crack movement. "It is apparent that the fabric reinforced test section and the control section behaved similarly and there is no evidence that the, stress relieving layer provided any advantage in preventing reflection cracking." The pavement showed significant evidence of joint faulting and pumping. April '72 joint deflections tests were initiated. State found that when deflections were zero the fabric had a marked effect on reflection cracking as seen by the fact that of 20 treated joints none were cracked while the control section had 4 to 9 joints cracked. Also when deflections = .002 inches reflection cracks were 29 percent in the fabric sections and 54 percent in the control section. When deflections were over .008 inches all joints had reflection cracks (fabric and control). It is likely the fabric had no ability to distribute shear stresses and was unable to significantly reduce reflection cracking. 5 inch cores over cracks (September 1974) showed that the fabric was still firmly bonded to the asphaltic concrete and the fabric showed no evidence of damage. (No tear or elongation). No cases of pumping were observed. 2. Both fabrics (chemstrand was also used) were somewhat effective in at least delaying reflection cracking. As of September 1975 reflection cracking percentage in the Petromat section were: Traffic lane - 71 percent; Middle lane - 55 percent; Passing lane - 33 percent. CONCLUSIONS BASED ON STUDIES: 1. Neither sand as a bond breaker nor high strength fabrics as stress relieving layers are effective in reducing reflection cracking where vertical joint movement (differential deflection) is a significant factor. 2. When differential deflections are greater than about 0.002 inches reflection cracks form very early. Such cracking is delayed for lower differential deflection but may occur as the magnitude and frequency of wheel loadings increase.

STATE	Description of Installation	Date of Construction	Conclusions - Recommendations - Comments
Virginia (Continued)			3. Petromat is able to sustain formation of reflection cracking in the overlay without damage to itself. 4. The asphalt impregnated fabric over joints in old pavements beneath an overlay may be effective in reducing infiltration of surface water to pavement sub-layers. There is some evidence that pavement pumping may be reduced by this method. 5. The two fabrics tested (Petromat and Chemstrand) can delay the formation of reflection cracking. There is strong evidence, however, that such cracking is fatique in nature and will eventually develop under repetitive wheel loadings. RECOMMENDATIONS: 1. Stress relieving layers of thin fabric used to reduce reflection cracking are not recommended where there is any appreciable differential vertical movement of joints or cracks to be overlayed. 2. Petromat is recommended for installation on an experimental basis for either of the following uses: (a) To reduce reflection cracking in instances where truck traffic will not be a factor. (b) To reduce the infiltration of surface water into transverse cracks in instances where it is not feasible to provide a positive sub-surface drainage system.
North Carolina	U.S. 70 Hillsborough Overlay of Old PCCP	Late 1972	Series of 510 foot sections. Each treatment repeated 6 times for statistical evaluation. Latest detailed survey conducted 6/77 by N.C. State University, N.C. DOT and FHWA Division. Strictly a reflection cracking study. Reflection cracking has increased a great deal in the past year. No clearly superior treatments evident. "... Fabric treatments as a group do not appear to be superior to" other non-fabric treatments (A-Mat course of #5 stone; B-Opengraded Mix; C-2 I-2 plant mix; D-Sand Seal) Petromat, one of four synthetic fabrics being tested.
North Dakota	I-94-8(64)315 - Casselton to Buffalo. Petromat was laid full width, out to out, of shoulders, 14,600 feet in length.	3/72	As of Feb. 1975 the control section was the better section. The reflection cracking in the Petromat section generally paralleled crack development in the control section but with the control slightly better. No final report has been received on this project. The original roadway, built in 1948, was portland cement concrete pavement with 15 foot joint spacing.
Pennsylvania	100 percent State funded project Linglestown Road, Harrisburg	10/73	Six foot wide strips were placed and 200 square yards were used. Original pavement was badly alligator cracked with deep rutting, up to 1 inch. Carries heavy truck traffic. Latest verbal report (via telephone 10/25/77) advises: State still looking at it. Has successfully prevented cracks from coming through. State personnel want to try it on a larger project. No report planned.
Wyoming	I-25, Casper North. Petromat was placed full width including 2 foot inside shoulder with a 24 foot roadway. Constructed over asphaltic concrete. Overlay: 4" of Type II hot plant mix pavement and a 3/4" wearing course. Control section was the same except for Petromat.	4/72	Petromat sections and control both developed "identical" crack spacing indicating a failure of Petromat to reduce cracking. Petromat delayed cracking through the fall of 1973. Following the winter of 1973-74 it was reported: "Visual observations here shown that the Petromat section has lost its ability to control cracks since this section now has the same amount of reflective cracking as the control section. The Petromat apparently failed during the cold period encountered during the past winter.

STATE	Description of Installation	Date of Construction	Conclusions - Recommendations - Comments
Yosemite Valley California (Yosemite Park)	Old roadway was badly deteriorated. Alligator cracks and holes. Cracking in all directions. Petromat and Petroset applied. Control: 3 inch overlay. Petromat section: 2 inch overlay. 6 test sections (Petromat).	4/71	At the time of the last inspection by an FHWA Federal Projects engineer on November 1973 no cracks were evident in the fabric sections while the control sections had reflected cracks. Cores taken from both the test and control sections were tested for density and it was found that densities over the fabric averaged 4 p.s.i. higher than densities in the control sections.

TABULATION OF EXPERIMENTAL PROJECTS

Ongoing as of December 1977 with "PETROMAT" as a Test Feature
(Projects not previously included in any summary)

New Projects - Petromat	Test Features	Evaluation Procedures	Results-Remarks-Observations
CALIFORNIA			
M-6005(3)--Arlington Avenue, Riverside, Installed: 1976	36,245 sq. yds. of Petromat under 1 1/2 inches of AC. Three control sections. ADT: 22,000	Observations and periodic evaluations for 2 years.	July 1977 detailed inspection: few random cracks in control section - none in Petromat.
M-5047(001) 07-LA-47 Route 47 Installed: August 1976	2 inches AC with and without Petromat.	Existing cracks plotted - annual observations with photos for 5 years.	No performance information to date.
M-6000(003) 08-SBd-0-CHn Central Ave., Chino. Installed: April 1974	0.15 feet AC overlay with Petromat - over 0.04 foot leveling course.	Periodic inspections - apparently no precise crack counts made.	As of 11/75 no reflective cracks - pavement performing well.
F-001(13) Ora-1-1.1/4.9 + 29.7/33.7 Orange County	0.08 foot AC over Petromat - (4 miles 10 feet wide).	Periodic inspection - observation & photos for 5 years.	No performance data.
F-074(3) Ora-74-1.9/6.0 Orange County	0.08 foot AC over Petromat - (4 miles 10 feet wide).	Periodic inspections - observation & photos for 5 years.	No performance data.
TQM-5001(12) 07-396744 Orange County - Installed: 8-9/77	0.08 foot AC over Petromat - (4 miles 10 feet wide).	Periodic inspections - observation & photos for 5 years.	No performance data.
M-F-364(3) Herndon Avenue (Blackstone Ave. to Villa Ave) Not yet installed. Urban project.	Not indicated.	Periodic inspection - observation and photos for 5 years and deflectometer tests for 5 years.	Construction scheduled for October 1977 through Jan. 1978.
I-10-4(24)148 11-RIV-10 Coachella Canal Bridge to Chiriaco Summit, east of Indio. Not yet installed.	Outside lane only, Petromat under 0.08' AC plus 0.05' OGAC and Petromat under 0.16' AC plus 0.05' OGAC. Normal overlay: 0.22' AC plus OGAC in travel way.	Checklist of items to be included in evaluations is comprehensive. Post construction evaluations include crack counts, photos, deflections, investigation of unusual conditions. Yearly reports.	Had not been advertised as of June 1977.
TQF-P078(8) - 11-SD-78 Project not yet started (7/77).	Petromat under 0.15' AC. Control: 0.15' AC and 0.30' AC. Petromat under transition: 0.15' to 0.30' AC.	Existing road conditions have been surveyed and evaluated. Construction and post construction evaluations to be conducted.	Construction was to begin in July 1977. Petromat used in outside traffic lanes.
RF-P086(9) - 11-IMP-86 To be advertised in 8/77	100 feet Petromat section with 0.15' AC overlay. Control Sections: 0.15' AC overlay and 0.30' AC overlay.	Existing road conditions have been surveyed and evaluated. Construction and post construction evaluations to be conducted.	Bids were opened 9-8-77. Existing asphalt overlay is cracking extensively in outside lane.

New Projects - Petromat	Test Features	Evaluation Procedures	Results-Remarks-Observations
CALIFORNIA			
RF-007-7(23) 04-SCI-101 Sargent OH to Carnadero Creek - Installed: 7/76	One mile, north & southbound outer lanes. Replacement of 0.1 foot of AC overlay with Petromat. Total overlay thickness is not indicated.	Condition survey 1 year after construction. Final survey and evaluation 2 years after construction.	No performance data. Objective: determine practicality of reducing overlay thickness with Petromat.
M-6002(006) 07-LA-2, 405 Route 2 LA County, Sawtelle Boulevard to Greenfield Ave. and on Route 405, north and south of Route 2. Installed: 1977 ?	5,000 yards of Petromat over existing badly cracked AC, 0.7 feet thick, over native material with low R value. Overlay thickness not specified.	Crack counts before and after. Periodic inspections for 2 years.	No performance data.
F-078(6) 11-SD-78 Rte. 78 San Diego County Ritchie Road near Wynola to Main Street in Julian. Installation scheduled: July 1977	2-200 foot Petromat sections with 0.15' AC overlay; 1-200 foot tapered thickness section (0.15'-0.35' AC) over Petromat; Controls, 0.25 AC (200' section) and 0.35' AC (200' section).	Before and after evaluation. Construction report & evaluations to be performed by District 11 Transportation Laboratory.	Original pavement: PCCP 18' wide. Had been overlayed and widened (no date furnished). 2 lane road. ADT: 2,000. Mountainous terrain subject to freezing temperatures.
F-078(2) F-111(1) 11-Imp.-78, 111 Rte 11 - City of Brawley. Installation: 1977	Petromat plus 1 inch overlay of AC No thickness for the control section was cited.	Construction report plus followup evaluations.	Existing pavement is very badly cracked. Cracks to be sealed with sand and oil.
M-5011(007) 07-LA-11 - In Los Angeles. Pasedena and South Pasedena. Project not yet advertised in early 1977.	Petromat to replace 0.1' of AC. No specific overlay thickness are presented. Leveling course to be placed prior to Petromat and overlay (no dimensions given).	Before and after crack surveys. "After" crack surveys to begin 2 years after construction and to be performed annually thereafter.	Reconstruction of 35 year old AC pavement. Short fast construction operation required.
COLORADO			
MU-0026(2)--Alameda Avenue - I-25 to Morrison Road. Installation to be accomplished.	Fabric plus 1 1/2" AC overlay. Control: 1 1/2" AC overlay. 4 lane highway ADT: 30,000 (1976).	Before and after crack surveys. Surveys twice per year for minimum of 3 years. Final Report.	Test sections are 250 feet long arranged so as to provide side by side comparison with control section. Other test feature: Asphalt-rubber-stress absorbing membrane.

New Projects - Petromat	Test Features	Evaluation Procedures	Results-Remarks-Observations
FLORIDA			
I-4-1(78)25 - Eurika Springs Road to SR-39. Overlay over PCCP. Installed: 1977 ?	100 lbs/sq yd Type III AC leveling course under Petromat under 2" Type S-1 AC and 5/8 inch friction course Type 2. (Bidim also a test feature on this project).	In accordance with FHPM 6-4-2-4. Category 2. 5 year study.	Original pavement: 9" PCCP over 12" stabilized subgrade. Pavement is 15 to 20 years old. PSI values range 2.3 to 4.2 (fair to good) Subgrade: silty sand with clay and muck pockets.
GEORGIA			
I-85--Southbound lane Gwinnett, Resurfacing over PCCP.	Maybe several projects. Clarification needed.	No Information	Research Project No. 7502 includes: concrete and asphalt overlays; edge drains and no edge drains; Petromat Mirafi, Bituthene test sections.
ILLINOIS			
F-505(1)--Stephenson County, Freeport Project scheduled for 8/77 letting.	Petromat under 2,1-inch AC lifts. 1321 sq. yds. of Petromat.	Photos during construction to record installation procedures and problems. Photos before and after. Two year evaluation. Semi-annual inspections.	Two inches of the existing pavement is to be removed and replaced with 2,1-inch lifts of AC.
F-760( ) - South of Fullerton DeWitt County	50" wide strips of Petromat over widening joint - 2,671 long 1 1/2" binder (1st course) followed by Petromat and 1 1/2" AC overlay.	Not Indicated	Also included: Mirafi at 44 inches wide. Tack coat: AC 85-100.
KANSAS			
Route US-50--Ford County F050-2(40)	Petromat strips over cracks plus 1 1/2" BM-2 and 3/4" BM-1 overlay.	Low level aerial phots before. Construction monitored. Twice first year crack surveys will be made. Additional aerial photos may be taken. Annual crack surveys for 10 years.	Rebound deflections of existing pavement range: .026-.108;severe cracking existing;some complete failures. Rebound range:.034-.073 surface good except for rutting and shoving at cracks. Rebound range: .020-.96.
Route K-4--Jefferson County RF 068-3(18)	1 1/4" AC plus-Petromat plus 1 3/4" AC overlay on 1,000' section,control: 3" AC.	Low level aerial photos before. Construction monitored. Twice first year crack surveys will be made.	Rebound deflections of existing pavement range: .026-.108;severe cracking existing;some complete

New Projects - Petromat	Test Features	Evaluation Procedures	Results-Remarks-Observations
KANSAS (continued)			
Route US-75--Coffey County F063-2(31)	6.7 miles - Petromat plus 3" BM-2 overlay on 1,000' section.	Low level aerial photos before. Construction monitored. Twice first year crack surveys will be made. Additional aerial photos may be taken. Annual crack surveys for 10 years.	Rebound deflections of existing pavement range: .026-.108;severe cracking existing;some complete failures. Rebound range: .034-.073 surface good except for rutting and shoving at cracks. Rebound range: .020-.096.
RF-021-2(5) Parts I & II. North of Hodgeman-Ness County line in Ness County. Installed: late '76 or early '77.	Two 1,000' sections with Petromat (Two 500' sections with Typar, also) Existing pavement to be topped with 2 thicknesses of bituminous base (BM-4): 1 1/2 and 2 1/2 inches. Petromat placed on both thicknesses followed by 1 1/2 inches AC (BM-2 or 3).	Not specifically noted.	Contract awarded 6-7-76. Each section is about 24.5 feet wide.
LOUISIANA			
FLH Project 59-1(3) Scenic Longleaf Trail Kisatchie National Forest. Sections completed: August 1975	600 feet of Petromat; 9' to 22' wide. On 6" portland cement stabilized base and under 2" AC surface course.	Before and after crack counts and measurements. Construction report with photos (April 1977)	Observations in April 1977: Stress relieving interlayer like Petromat can reduce reflection crack from cement treated bases. Observations are continuing.
MISSOURI			
River Front I-35 to Front apparently located in Kansas City	8,000 sq. yds. Petromat plus 1 3/4" overlay and 100' control section.	Before and after crack recordation. Annual surveys. Five year study.	No indication of installation date.
Sterling at I-70 apparently located in Kansas City	1,560 sq. yds. Petromat plus 1 3/4" overlay and 100' control section.	Before and after crack recordation. Annual surveys. Five year study.	No indication of installation date.
Red Bridge - Holmes to R/R East apparently located in Kansas City	3,740 sq. yds. Petromat plus 1 3/4" overlay and 100' control section.	Before and after crack recordation Annual surveys. Five year study.	No indication of installation date.
North Oak - Vivion to Englewood apparently located in Kansas City	16,000 sq. yds. 2 to 3 inch wedge course plus Petromat plus 2" overlay.	Before and after crack recordation. Annual surveys. Five year study.	No indication of installation date.

New Projects - Petromat	Test Features	Evaluation Procedures	Results-Remarks-Observations
NEVADA			
I-080-4(41)254--3 miles east of Lander Eureka County Line to 2.6 miles west of Emigrant Summit (Northeastern Nevada). New project, may not yet be installed.	5,000 feet of Petromat replaces 1" Plant mix Bituminous surface portion of overlay. Travel lanes only, 24' wide. Overlay: 1 1/2" Plant mix Bituminous Surface and Plant Mix Bituminous Open-Graded Surface.	Low level aerial photos (before). Periodic inspections with core samples, construction review and report.	Existing cracks filled prior to overlay with "rubberized asphalt". Work plan was approved April 1977. No knowledge that it has been constructed.
NEW MEXICO			
I-025-2(35)89 and I-025-2(37)112	8,133 feet, full width with 85-100 pen. AC tack. Control: 1" plant mix plus 5/8" seal coat. Overlay on Petromat?	Construction inspection and report. Post construction monitoring on 3 month intervals initially. Expect answers in 1 to 2 years.	Mirafi 140 and rubber-asphalt seal coat also included. All existing cracks > 1/4 inch to be sealed with 120-150 pen. AC.
NORTH DAKOTA			
DP-RF-1-083-(12)145 McLean County	1,300 feet by 27 feet wide Petromat over cracked AC. No indication of new overlay thickness.	Crack count "before." Particular note will be made of cracks 1/8 inch and wider. Construction review with photos. Periodic crack counts. 3 years.	Evaluations each spring. Roadway being widened and resurfaced to upgrade geometrics and restore riding quality.
OKLAHOMA			
I-40-3(39)086--Custer-Caddo County Line east in Caddo County. Installed: late 1976	Existing pavement: (top down) 1 1/2" type C AC; 3" type A AC; 8" stabilized aggregate base; 6-10" of select subbase. Fabric in eastbound lanes followed by 1" type C leveling course and 3/4" opengraded friction course.	Extensive crack mapping before and after. Resurveys 30 days after construction; 6 months after first survey; every 12 months after.	6 test sections with Petromat 12' wide. Other sections include Mirafi fabric (8 sections).
F-186(89)--McIntosh County (US-69) 1 mile north of Onapa. Installed: July 1974	1,000 feet on northbound lanes of US-69. Overlay 2 inches type C asphaltic concrete.	No Information	No Information

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New Projects - Petromat	Test Features	Evaluation Procedures	Results-Remarks-Observations
OKLAHOMA			
FR-1-35-4(82)232--Kay County (I-35) 1 mile sough of Stateline (SB Lane) Installed: May 1975	3,000 feet (500 foot sections) of Petromat between Type A and Type C AC layers, southbound lanes (both).	No Information	No Information
Tulsa County (I-35) 1 mile west of US-75. Installed: November 1973	No Information	No Information	No Information
TEXAS			
IR 40-1(97)051--0.3 miles west of Potter County line to 2 miles west of Bushland. Installation scheduled: 1977	No Information	No Information	No Information

AD-A073 484 FEDERAL AVIATION ADMINISTRATION WASHINGTON DC SYSTEM--ETC F/G 13/2
REFLECTION CRACKING OF BITUMINOUS OVERLAYS FOR AIRPORT PAVEMENT--ETC(U)
MAY 79 A L MCLAUGHLIN

UNCLASSIFIED FAA-RD-79-57 NL

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SUPPLEMENTARY

INFORMATION

U.S. Department
of Transportation
Federal Aviation
Administration

800 Independence Ave., S.W.
Washington, D.C. 20591

SEP 1 1981

The enclosed errata sheet is intended to replace page 42 of Federal Aviation Administration Report No. FAA-RD-79-57 dated May 1979 entitled Reflection Cracking of Bituminous Overlays for Airport Pavements, A State-of-the-Art. A copy of this report was sent for your information and retention in September 1979. We would appreciate if you would block out page 42 of the original report and insert the errata sheet in its place.

Sincerely,

Aston L. McLaughlin

ASTON L. MCLAUGHLIN, ARD-530

Enclosure

resistance was demonstrated in these tests, research to investigate the effectiveness in retarding reflection cracking is said to be necessary.

The following are some conclusions reached by others concerning fabrics in overlay projects. They are quoted from a report addressed in the memorandum already mentioned.

> " The conclusions reached in 1976 regarding the effectiveness of Petromat when used with thin asphalt concrete layers are still valid for alligator-type cracking. Petromat covered with 1" of asphalt concrete performs about equal to a 2 inch mat without Petromat. In some cases this has provided a 100 percent increase in the life of the overlay.
>
> The performance of thicker lifts of asphalt concrete, 2" or more, over Petromat have not been adequately evaluated as yet because the life of 2" or more overlays greatly increases the life of the overlay without Petromat. Some projects are in progress but it may take 2 to 3 years before data is available for a decision.
>
> The performance of Petromat over asphalt concrete transverse thermal cracks has not been as promising as it has over the smaller block or alligator-type cracks. Projects such as Route 395 near Doyle in California and I-20 near Odessa, Texas show definite improvement, particularly in the early years. As the pavements become older and the asphalt harder, transverse cracks begin to develop but at a slower rate than the controls.
>
> The use of 2" or thinner layers over Petromat on portland cement concrete have not proved effective as a crack retardant. The one year old Georgia I-85 experiment indicates that at least 4" should be used as a cover with Petromat (6" without Petromat). These relationships, however, may change with additional years of service.
>
> Petromat continues to give good service when used as a maintenance tool under a chip seal coat in both Texas and California.
>
> Evidence developed to date in experimental projects indicated that the average performance of materials such as Mirafi, Petromat, or Structofors is quite similar.